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ESKIMO VI MODEL TESTS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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This report contains the results from a series of high explosive tests designed to determine the blast loading from 1/50th scaled models of the type planned for exposure on Operation ESKIMO VI. A 1.27 kg charge was used to simulate 158760 kg in a full size storage magazine. Blast loading on structures located to the front, side, and rear of a donor magazine are presented. Correlation with other model studies and full scale tests were made and predictions for the blast loading to be expected on the ESKIMO VI one-half scale structures are made.

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I. INTRODUCTION

A. Background

The Department of Defense Explosives Safety Board (DDESB) has been an advocate and sponsor of scaled model studies being conducted at the U.S. Army Ballistic Research Laboratory (BRL) for several years. It was shown in Reference 1 that blast parameters from scaled donor models as small as 1/50th of a full size storage magazine could be correlated directly with results from full scale tests. In Reference 2, a study was conducted to document the blast loading on a scaled acceptor model, using a bare high explosive charge as the donor source. The objective was to aid in the design of the field operation ESKIMO V. In Reference 3 a comprehensive study was conducted in which both a scaled donor model and scaled acceptor models were used. Consistant results were obtained. The blast loads from an accidental explosion were established for munition storage magazines located at the current safe separation distances.

B. Objective

The objective of this project is to determine through the use of scaled models the blast loading that might be expected on the smokeless Powder/Projectile, Type II-B Munition Storage Magazine. The results will be used to design the field operation ESKIMO VI in which ½ scale storage magazines will be tested.

II. TEST PROCEDURE

The test procedure followed to meet the stated objective was first to design and construct the models; second, design the explosive source; and third, select the instrumentation system.

A. Model Magazine Design

The design and construction of the donor and acceptor models are described in the following sections.

1. The Donor Model

The donor models designed for this project were a 1/50th scale of the full size magazine. A sketch of the magazine is shown in Figure 1.

[1] *C. N. Kingery, G. A. Coulter, G. T. Watson, "Blast Parameters from Explosions in Model Earth Covered Magazines", Ballistic Research Laboratory Memorandum Report No. 2680, Sept. 1976 (AD#A031414).*

[2] *Charles Kingery, "Blast Loading on Model Earth Covered Magazines", ARRADCOM Tech. Report ARBRL-TR-02092, August 1978.* (AD #A061440)

[3] *C. Kingery, G. Coulter and G. Watson, "Blast Loading on Model Munition Storage Magazines", ARRADCOM Tech. Report ARBRL-TR-02140, Feb 1979.* (AD #A069086)

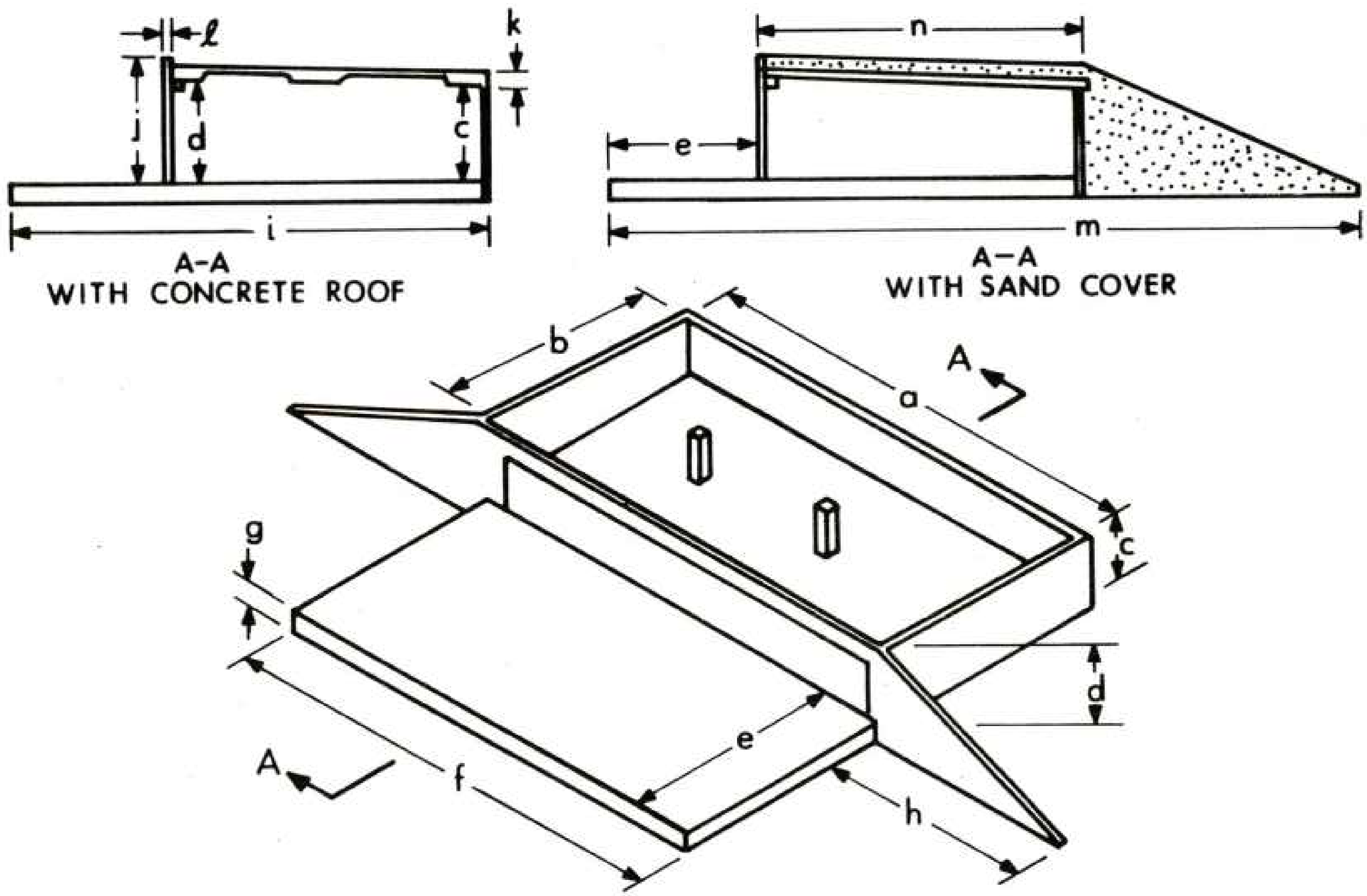

Figure 1. Sketch of the 1/50th scale donor model.

The dimensions associated with the letters in Figure 1 are listed in Table I for the full-size structure and the 1/50th scale model. The full-scale dimensions were taken from the Department of the Navy, Bureau of Yards and Docks Drawings 749771 through 749774 and 793751 titled Standard Magazine, Smokeless Powder/Projectile Type II B - 57 feet by 97 feet. The primary concern in the design of the donor model was the interior dimensions. Therefore, in Figure 1 the interior dimensions are stressed.

Table I. Dimensions of Full Size Structure and Donor Model

	Full-Size Feet	Full-Size Metres	1/50 Scale Metres
a*	95.0	28.96	0.579
b*	50.0	15.24	0.305
c*	13.0	3.96	0.079
d*	15.2	4.63	0.093
e	25.0	7.62	0.152
f	97.0	29.57	0.591
g	3.8	1.16	0.023
h	44.0	13.41	0.268
i	77.0	23.47	0.469
j	19.4	5.91	0.118
k	1.5	0.46	0.009
l	1.0	0.30	0.006
m	121.0	36.88	0.737
n	52.0	15.85	0.317

* Interior Dimensions

The interior walls and headwall of the donor model were 0.006 m (¼ inch) masonite. A photograph is presented in Figure 2. The roof was a scaled reinforced concrete slab designed to simulate the full scale storage magazine. The interior portion of the donor model with the concrete roof is shown in Figure 3.

The donor explosive must be emplaced after the model has been constructed in the field. Therefore a portion of the headwall was cut and hinged to allow insertion of the charge and detonator. This hinged headwall is shown in Figure 3.

When preparing the donor model for firing,a wooden form was placed over the interior portion as shown in Figure 4. A special modeling sand was packed into the wooden form giving a final configuration when the form was removed, and the sand smoothed, as shown in Figure 5. The sand used for the earth cover is 80 grit, and for each 45.4kg of sand a mix of 0.908kg of Actival (adhesive), and 0.908kg of Bentonite (clay), and 0.000946m^3 20 wt motor oil (1 quart) are blended to form a special modeling sand.

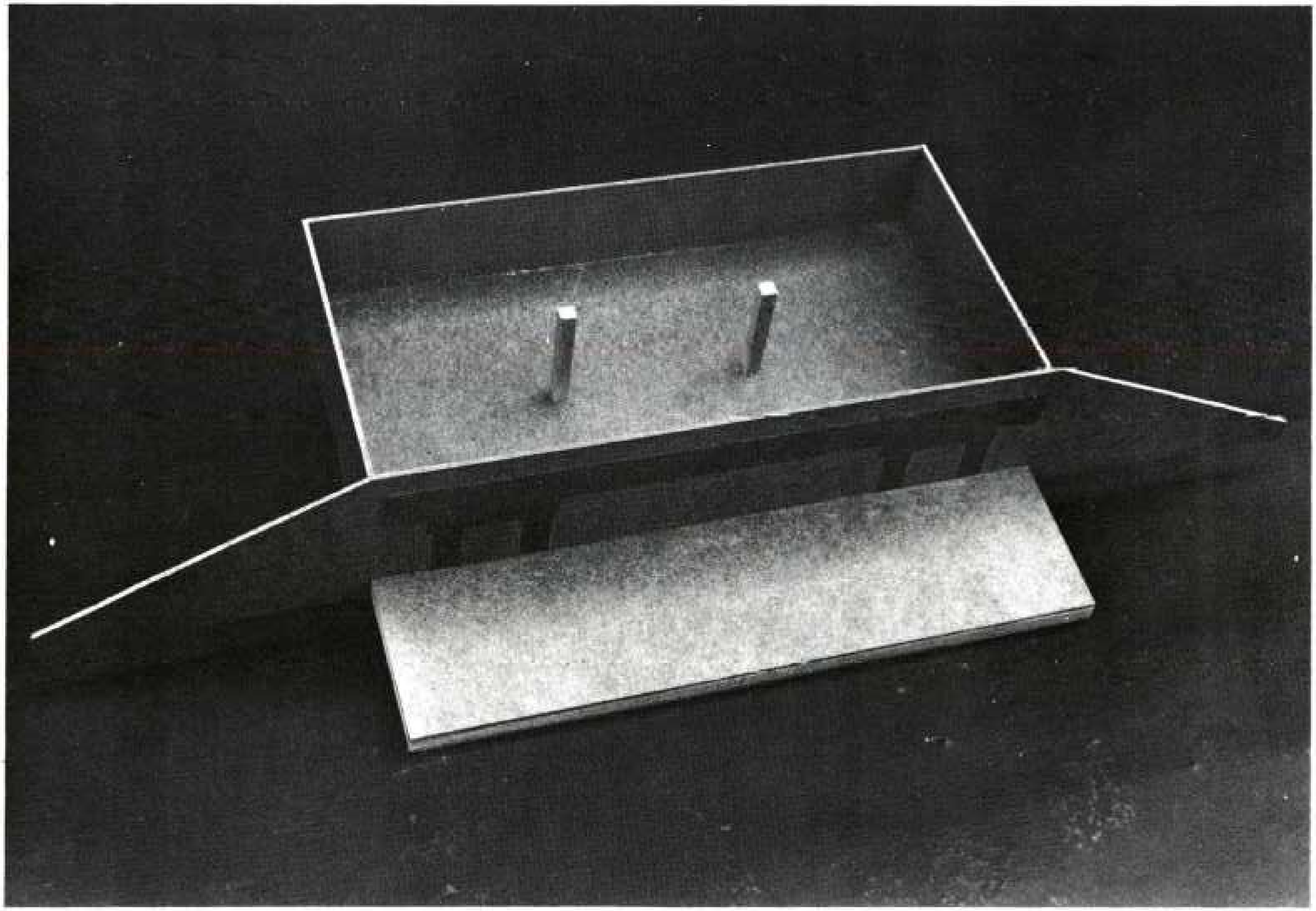

Figure 2. Photograph of the interior portion of the donor model.

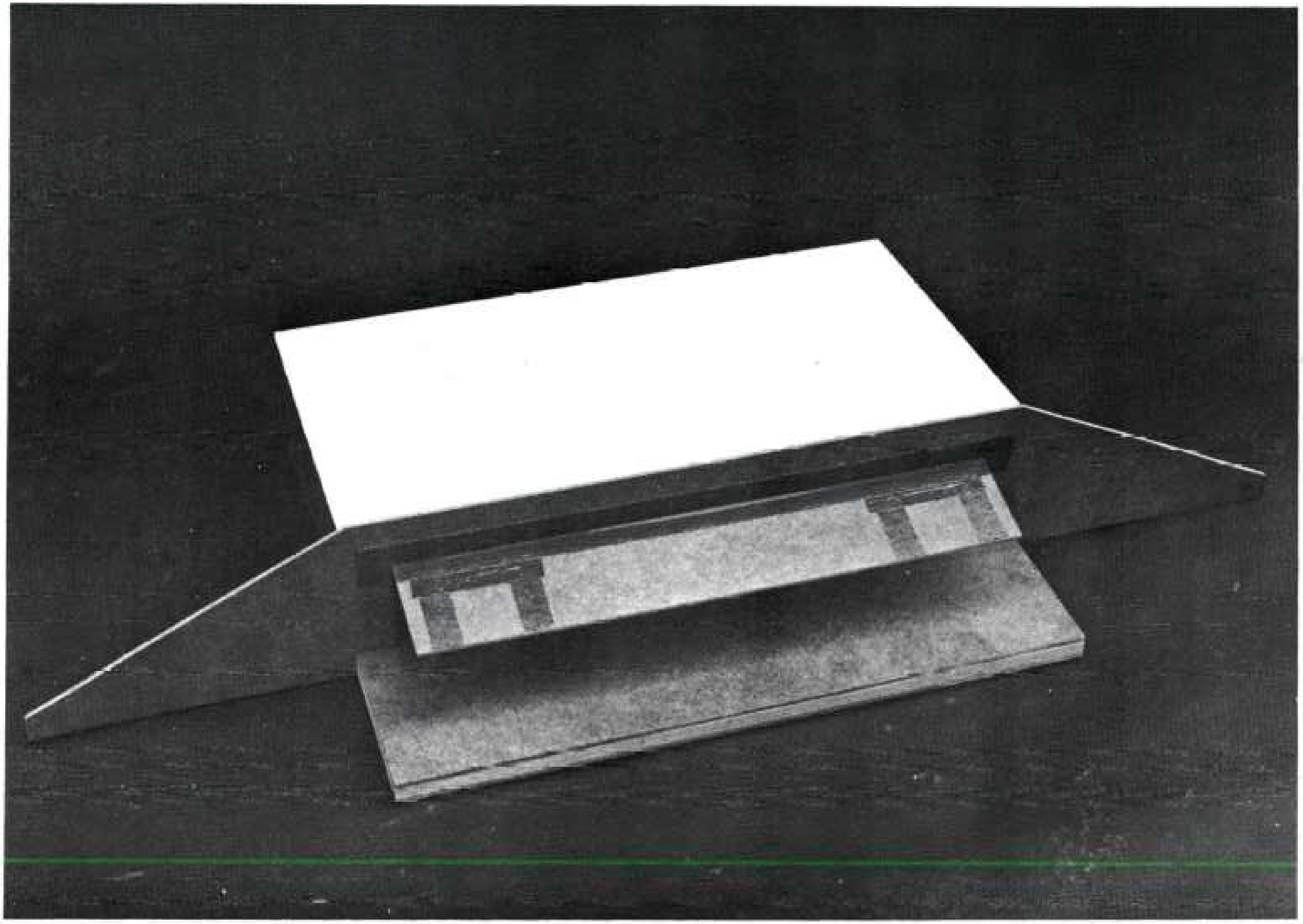

Figure 3. Photograph of concrete roof and hinged headwall.

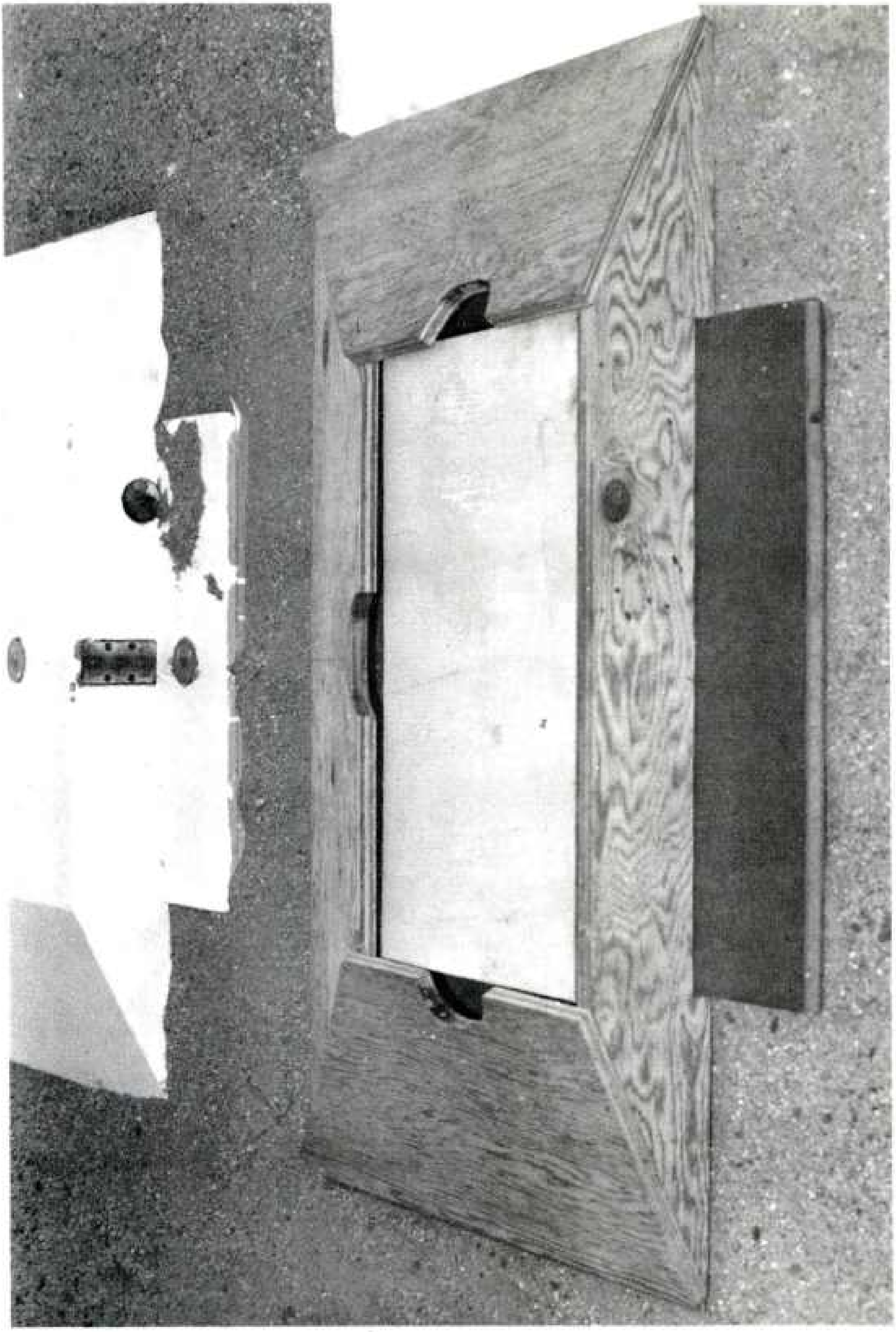

Figure 4. Photograph of wooden form for shaping the earth cover.

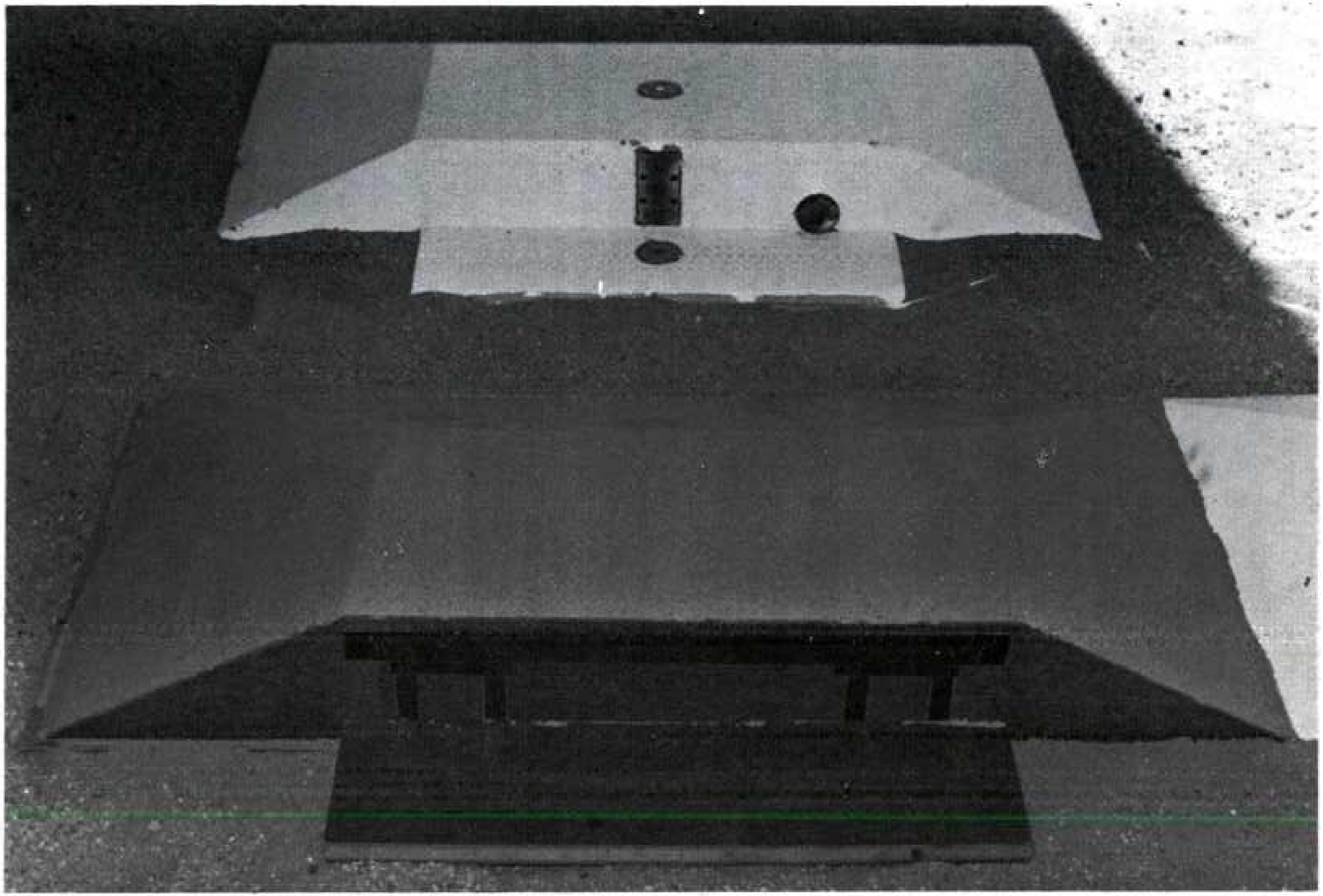

Figure 5. Photograph of donor model with sand cover.

Changes were made during the series of tests in the material used for both the headwall and the roof. These changes will be described in the Test Matrix Section of this report.

2. The Acceptor Models

There were three 1/50th scale, non-responding acceptor models constructed of cast concrete. The exterior dimensions of the full size structure including the earth cover were scaled down for the acceptor models. Special forms were constructed for each acceptor and the gauge mounts and cable conduit were cast into the concrete. The wooden form showing the gauge mounts and cable conduit for structure Model F is seen in Figure 6. The dimensions of the acceptor model can be found in Figure 1 and Table 1 but will also be given again in Section D of this chapter.

B. The Test Charge

For this project a special charge was designed. A 158,760 kg (350,000 pound) explosive source was designated as the full size charge weight to be considered as stored in the magazine. When scaling the linear dimensions of the structure by 1/50th, then the weight of the charge must be scaled by 50^3 or 125,000. Therefore the scale charge weight should be 1.27 kg (2.80 lbs). The charge was designed in the shape of an "H" in order to cover more floor area than a hemi-cylinder or hemisphere. The charge was cast in three units and assembled prior to placement. A drawing of the charge configuration is shown in Figure 7. The material is Pentolite and the detonator is inserted in the center of the crossbar. As noted in Reference 1, the ratio of the charge weight to storage volume should be maintained when designing a model experiment to represent a full-size storage magazine. The charge weight for the full-size structure is 158,760 kg and the volume is 1895.6 m^3 giving a charge weight to volume ratio of 83.75 kg/m^3. The scaled model charge was 1.27 kg and the volume 0.01516 m^3 giving a charge weight to volume ratio of 83.77 kg/m^3. The ratio was maintained.

C. Test Instrumentation

The test instrumentation system consisted of piezo-electric pressure transducers and magnetic tape recorders.

1. Pressure Transducers

Piezo-electric pressure transducers were used throughout the series of tests. The PCB Electronics Inc. Models 113A22, 113A24, and 113A28 with quartz sensing elements and built-in source followers were used exclusively.

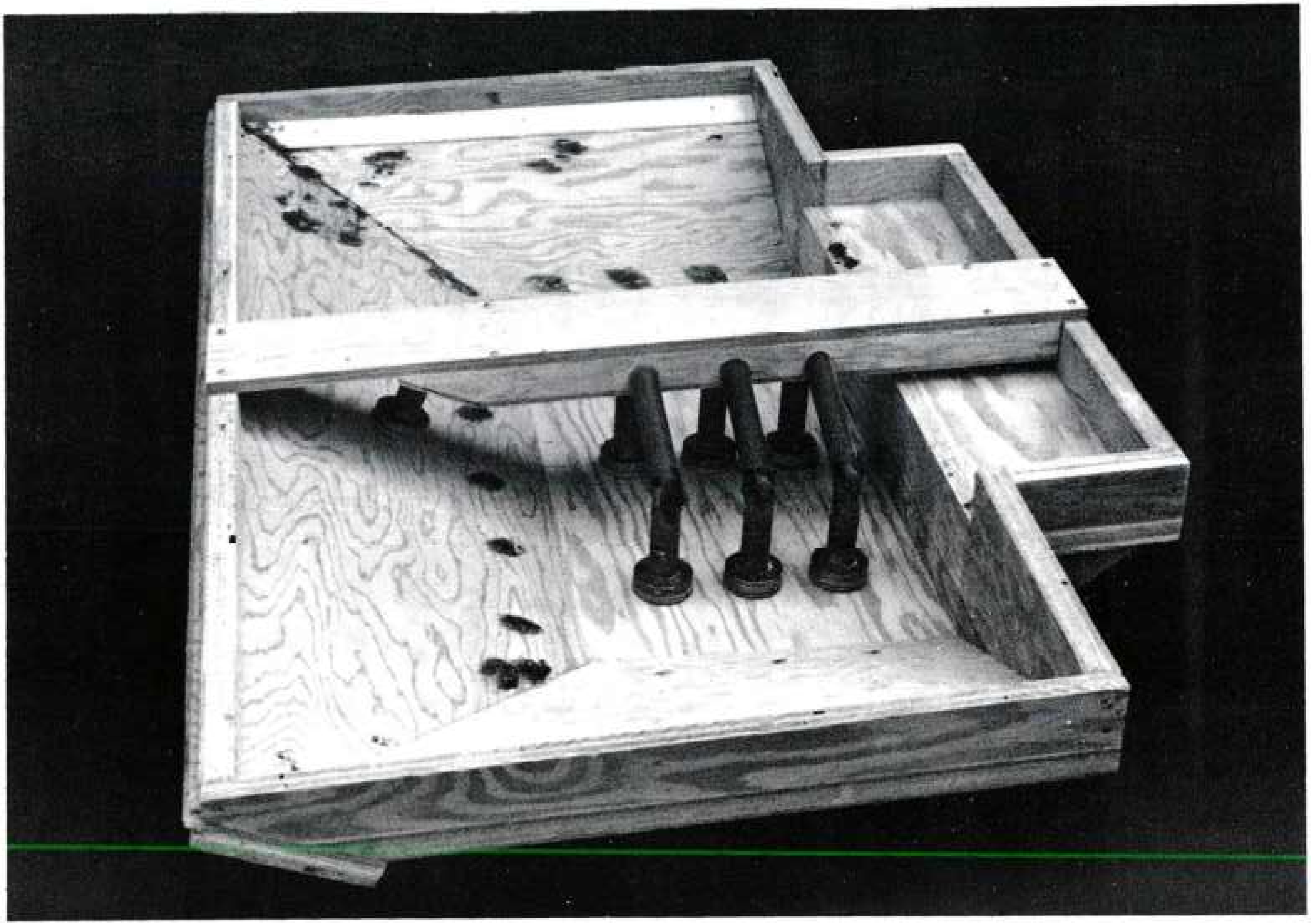

Figure 6. Photograph of wooden form showing gauge mounts and cable conduit for Structure F.

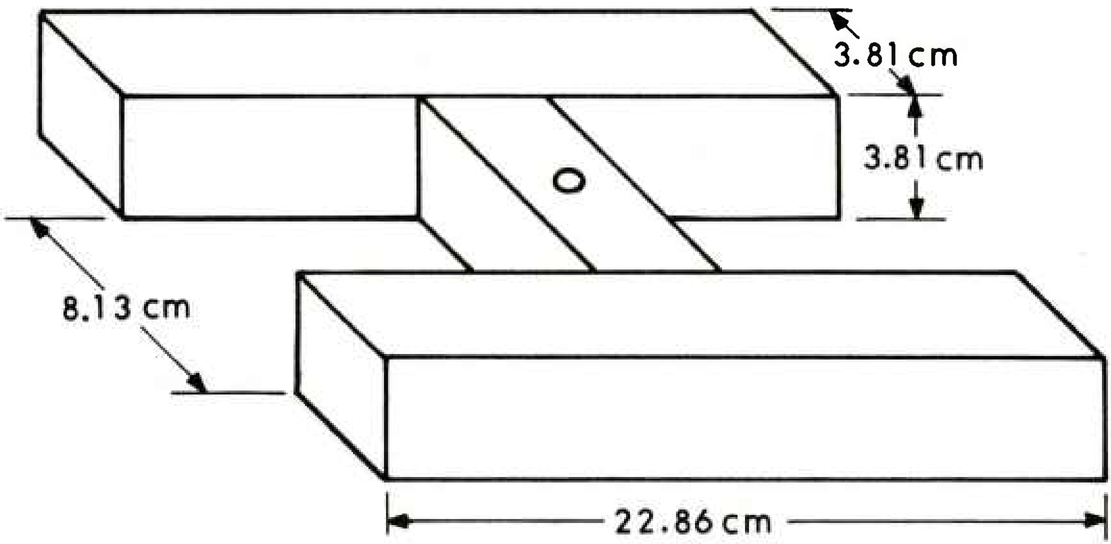

Figure 7. Charge configuration and dimensions.

2. Tape Recorder System

The tape recorders consisted of three basic units, the power supply and voltage calibrator, the amplifier, and the FM recorder. The FM tape recorder used was a Honeywell 7600 having a frequency response of 80 kHz. Once the signal was recorded on the magnetic tape it was played back and recorded on a Honeywell Model 1858 Visicorder. This oscillograph has excellent frequency response and the overpressure versus time recorded at the individual positions were read directly from the oscillograph playback for preliminary data analysis. For final analysis and reporting the magnetic tapes were processed through an analog to digital converter and then through a computer and plotting routine where the data were tabulated and plotted as overpressure and impulse versus time. The data gathering instrumentation system is shown in Figure 8.

D. Test Layout

The primary objective of this test series was to determine the blast loading on acceptor magazines located at established safe-separation distances to the front, side, and rear of a donor magazine. The safe separation distance in metres is defined as $0.8Q^{1/3}$ for magazines located to the front or rear of the donor and $0.5Q^{1/3}$ for side to side separation, where Q is the weight of explosive in kilograms stored in the magazine. The safe separation distance is measured from the interior wall of the donor to the interior wall of the acceptor. All gauge locations were measured from the geometric center of the donor magazine floor where the center of the explosive charge was placed. All charges were detonated at the center of the cross bar. The test layout showing donor and acceptor magazines is presented in Figure 9.

1. Acceptor Model F

The 1/50th scale model of the Type II acceptor magazine located to the front of the donor was designated acceptor model F. The safe separation distance $0.8Q^{1/3}$ for the 1.27 kg charge was 0.866 m. Model F was instrumented with seven pressure transducers as shown in Figure 10, with each gauge location preceded by the letter "F". All gauge positions relative to ground zero are listed in Table II.

2. Acceptor Model S

This model was placed to the side of the donor as shown in in Figure 9. The side to side safe separation distance is $0.5Q^{1/3}$. The safe separation distance for the 1.27 kg explosive source was 0.541 metres. Model S was instrumented with six pressure gauges. Although orginally planned for seven gauge stations, Position S-5 was deleted. Although shown in Figure 11, it was not instrumented and is not listed in Table II.

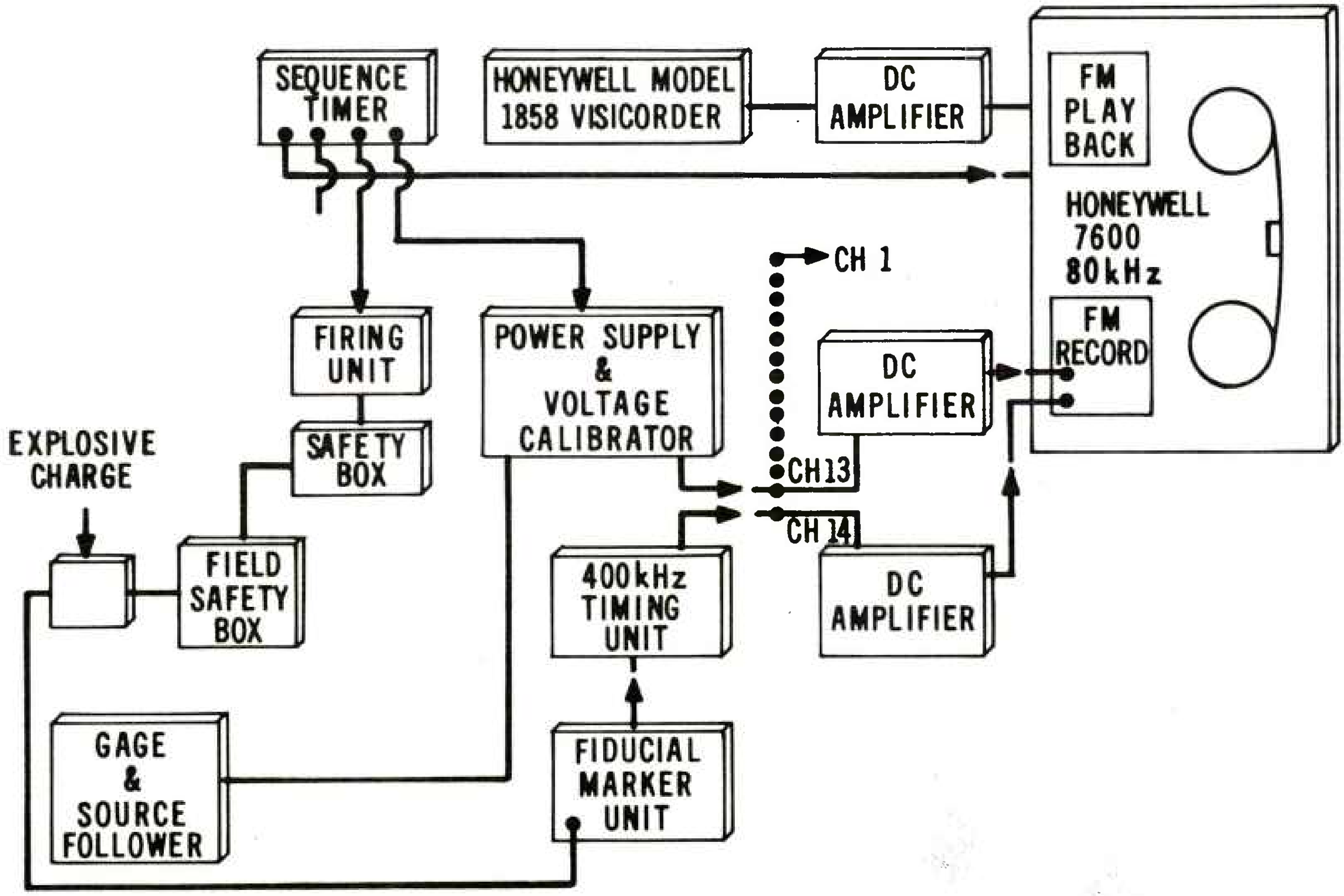

Figure 8. Instrumentation System.

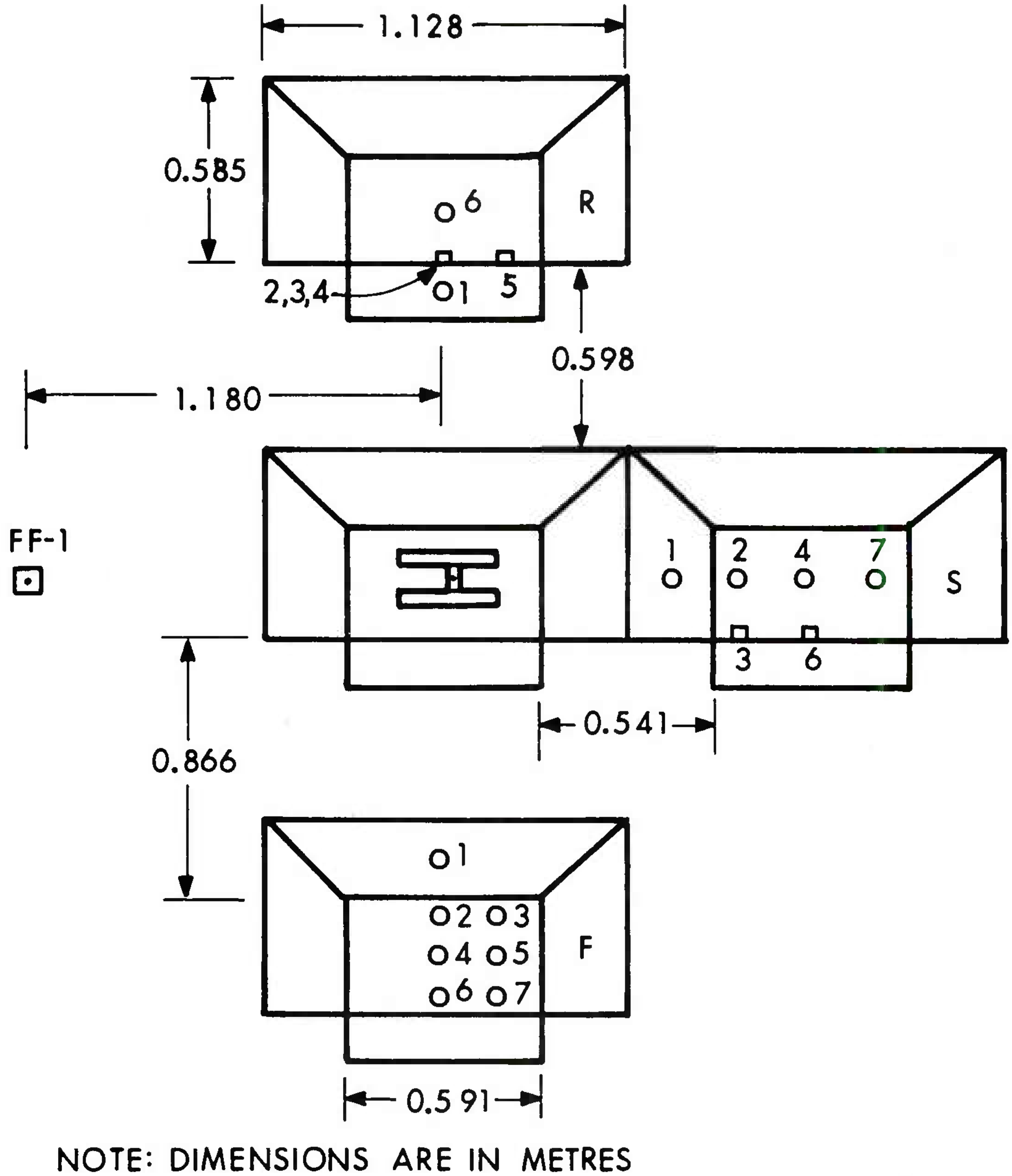

Figure 9. Test layout.

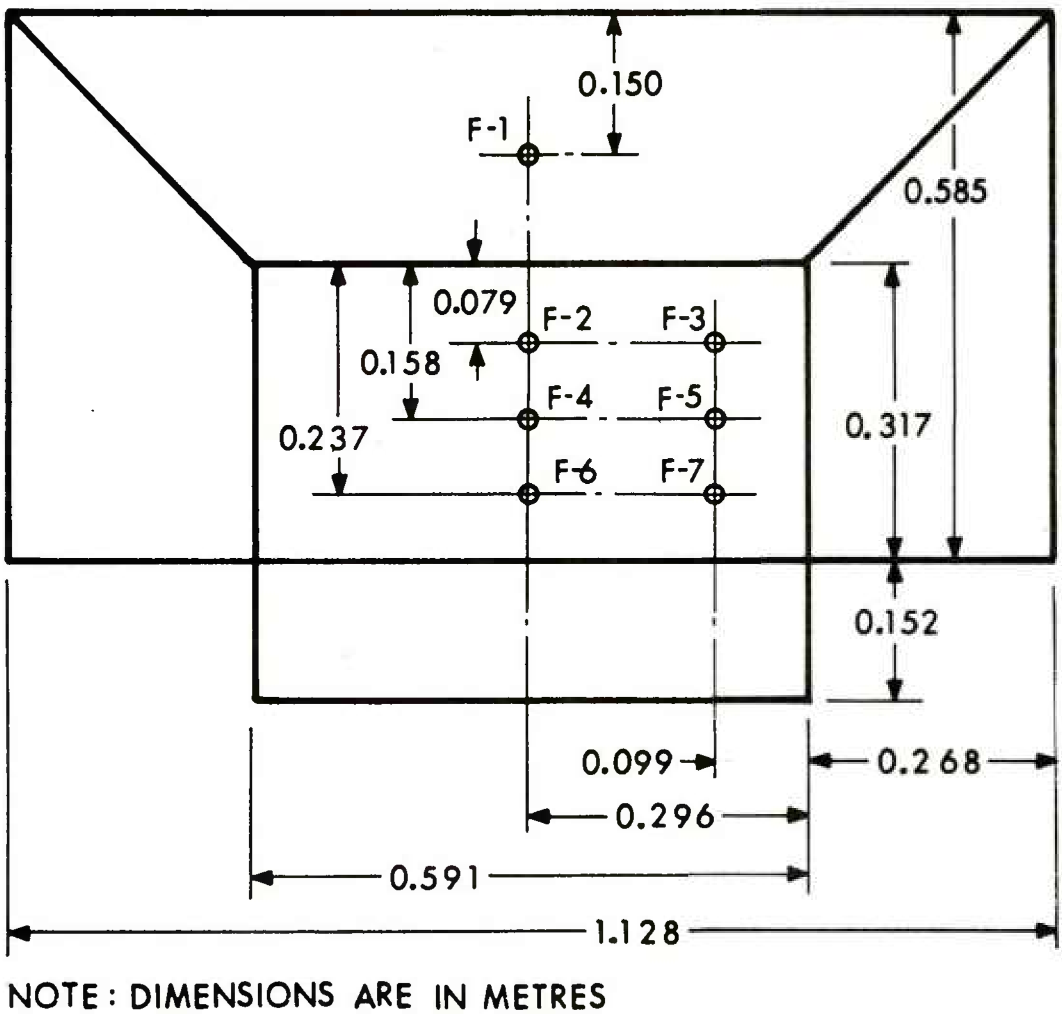

Figure 10. Gauge station locations on model F.

Table II. Gauge Distances from Ground Zero to Locations on Model Acceptors F, S, and R

Gauge Station	Full-Scale		1/50th Scale	
	Metre	Feet	Metre	Feet
F - 1	44.5	146.0	0.890	2.92
F - 2	55.2	181.1	1.103	3.62
F - 3	55.8	183.1	1.116	3.66
F - 4	59.1	193.9	1.182	3.88
F - 5	59.7	195.9	1.194	3.92
F - 6	63.1	207.0	1.261	4.14
F - 7	63.6	208.7	1.272	4.17
S - 1	34.9	114.5	0.698	3.29
S - 2	46.6	152.9	0.931	3.05
S - 3	47.4	155.5	0.949	3.11
S - 4	56.4	185.0	1.128	3.70
S - 6	57.2	187.7	1.143	3.75
S - 7	66.2	217.2	1.325	4.34
R - 1	48.2	158.1	0.964	3.16
R - 2	51.2	168.0	1.024	3.36
R - 3	51.2	168.0	1.024	3.36
R - 4	51.2	168.0	1.024	3.36
R - 5	52.2	171.3	1.043	3.42
R - 6	59.1	193.9	1.182	3.88
FF - 1	59.0	193.6	1.180	3.87

NOTE: FF-1 is a free-field gauge station.

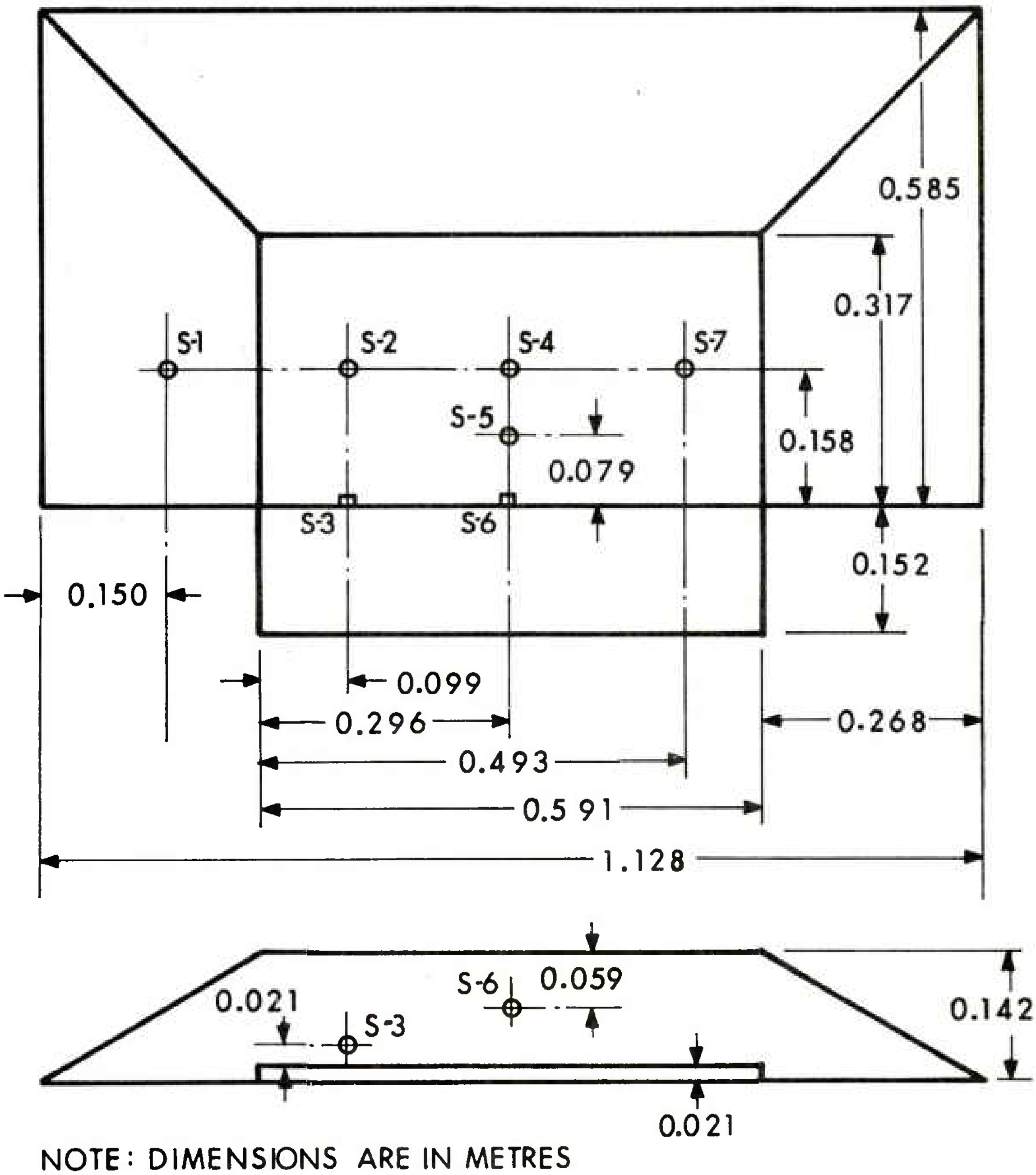

Figure 11. Gauge station locations on Model S.

3. Acceptor Model R

Model R was placed to the rear with the headwall facing the donor as shown in Figure 9. A separation distance of $0.8Q^{1/3}$ for a 1.27 kg charge was 0.866 metres. Model R was instrumented with six pressure gauges, four of which were on the headwall. The locations are shown in Figure 12. Distances from ground zero are listed in Table II.

E. Test Matrix

Three test firings were planned for this project but it became obvious after three shots there was a requirement for further testing because of the sensitivity of the blast propagating from the front of the donor to the confinement of the headwall. A description of the tests are described below.

Shot 1 - The headwall of the donor was hinged and lightly taped. The roof of donor model was a scaled reinforced concrete slab. Model R was inadvertently placed at a separation distance of 0.666 m, instead of 0.866 m.

Shot 2 - The headwall of the donor was heavily taped because of the excessive overpressures recorded on Model F. The donor roof was again a concrete slab and Model R separation distance was corrected to 0.866 m.

Shot 3 - The headwall consisted of two layers of ¼ inch masonite. Other donor parameters were held constant.

Shot 4 - Two changes were made on this shot. A plaster board material was used for the roof of the donor and a ¼ inch glass headwall was inserted in place of the masonite.

Because of the variation in pressure measurements on Model F and R a decision was made to plan two follow-on tests. For these tests, a modification was made to the donor model which allowed the insertion of a scaled reinforced concrete headwall in place of the masonite.

Shot 5 - This shot had a concrete roof and headwall with a slight modification of the charge configuration. The uprights of the "H" were 20.62 cm and the crossbar was 11.75 cm. The charge weight remained the same.

Shot 6 - The roof and headwall were the same as Shot 5 and the charge configuration was the same as Shots 1, 2, 3, and 4, as shown in Figure 7.

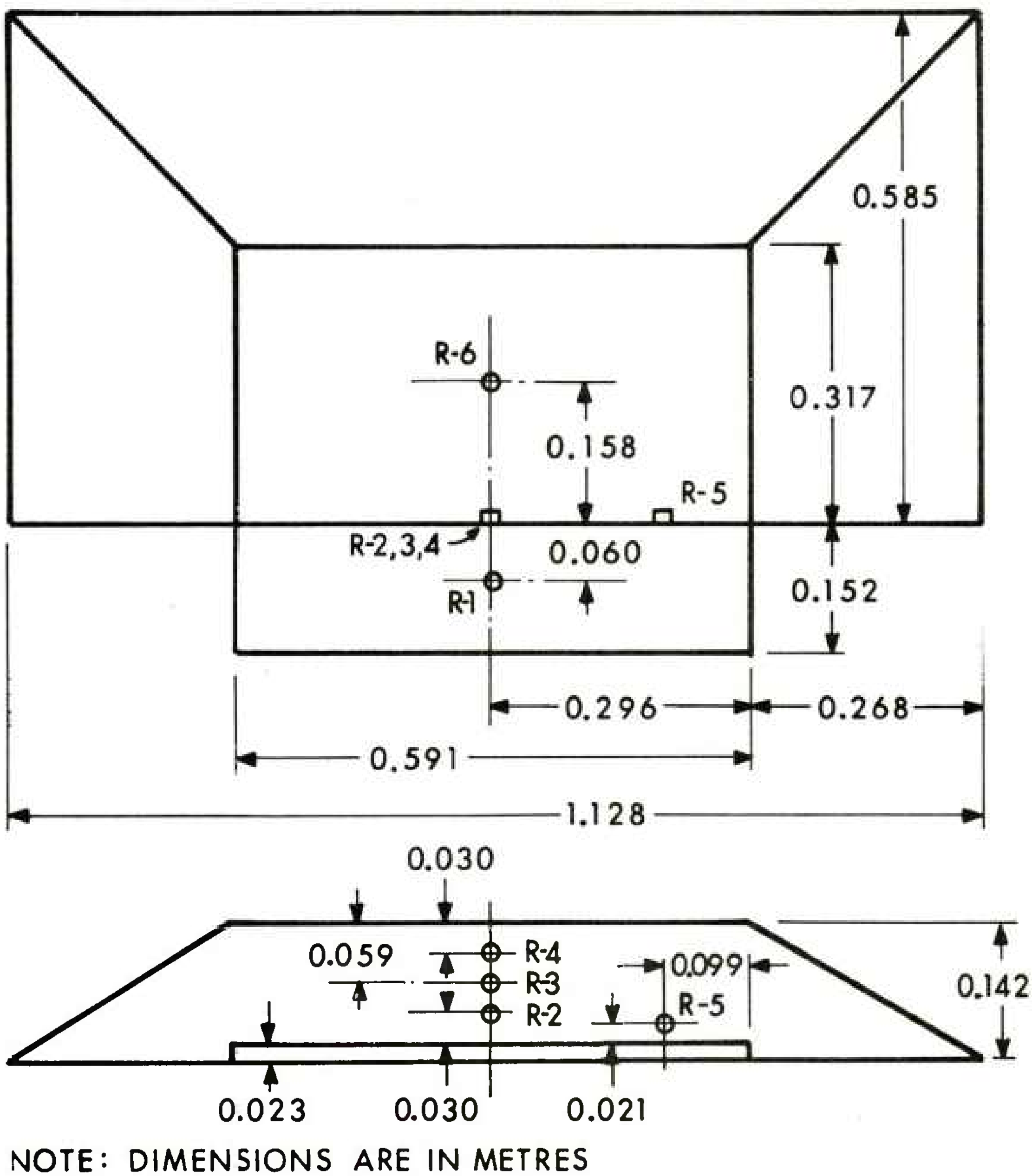

Figure 12. Gauge station locations on Model R.

III. RESULTS

The results will be presented in the form of tables listing shock arrival time, peak overpressure , overpressure duration, and overpressure impulse. Selected values believed most representative of the full scale conditions will also be presented in tabular form and plotted in the form of overpressure versus time at specific station locations. A separate table will be presented for each blast parameter so that direct comparisons can be made from shot to shot.

A. Blast Arrival Times (t_a) at Gauge Station Locations on Models F, S, and R

Model F was located to the front, Model S to the side, and Model R to the rear of the donor model as shown in Figure 9, with the gauge station location shown in Figures 10, 11, and 12. The blast arrival times (t_a) at gauge station locations on the three models are listed in Table III. The arrival time of the blast wave is the time interval between the detonation of the charge and the arrival of the blast wave at a specific location. It is a good indication of the repeatability of the shots as well as an indication of the magnitude of the peak overpressure.

When analyzing the t_a values listed in Table III, it is quite apparent that there is a wide variation in the shot to shot arrival times. This was expected in view of the changes made from Shot 1 through Shot 6. Average values of arrival time for Models F and S were obtained from Shots 1, 2, and 6 while on Model R they were determined from Shots 2 and 6.

B. Peak Overpressure (P_s) at Gauge Stations on Models F, S, and R

The values of peak overpressures (P_s) recorded at the gauge stations on the three models are listed in Table IV. When a gauge station recorded the arrival of two significant shocks both values are listed in the table with a "/" to separate them.

1. Peak Overpressures Recorded on Model F

In Table IV it can be seen that the peak overpressure propagating to the front of the donor and loading Model F is quite sensitive to the headwall material and charge configuration. Shots 1, 2, and 6 are considered similar and most representative of the loading to be expected on a full scale structure. Simple averages of the recorded peak overpressures for Shots 1, 2, and 6 are listed in Column 9 of Table IV.

Table III. Arrival Times at Gauge Station Locations on Models F, S, and R

Gauge Station Location	Distance From GZ m	Shot Number 1 ms	2 ms	3 ms	4 ms	5 ms	6 ms	SHOT (1+2+6)/3 ms
		Arrival Time, t_a						
F - 1	0.890	0.278	0.318	0.383	0.541	0.346	0.438	0.345
F - 2	1.103	0.400	0.431	0.528	0.581	0.477	0.549	0.460
F - 3	1.116	0.429	0.470	0.564	0.744	0.564	0.571	0.490
F - 4	1.182	0.459	0.485	0.564	0.812	0.526	0.616	0.520
F - 5	1.194	0.515	0.531	0.654	0.829	0.656	0.646	0.564
F - 6	1.261	0.515	0.546	0.646	0.897	0.594	0.673	0.578
F - 7	1.272	0.556	0.576	0.684	0.895	0.684	0.705	0.612
S - 1	0.698	0.538	0.585	0.614	0.514	0.516	0.664	0.596
S - 2	0.931	0.744	0.795	0.685	0.812	0.752	0.893	0.821
S - 3	0.949	0.740	0.765	0.699	0.857	0.872	0.955	0.820
S - 4	1.128	1.000	1.077	1.213	1.203	1.078	1.177	1.085
S - 6	1.143	1.054	1.085	1.449	1.186	1.180	1.248	1.129
S - 7	1.325	1.300	1.376	1.462	1.376	1.301	1.447	1.374
								(2+6)/2
FF - 1	1.180	---	1.286	1.333	1.353	1.331	1.280	1.283
R - 1	0.964	0.823	1.238	1.328	1.108	1.302	1.312	1.275
R - 2	1.024	0.893	1.316	1.401	1.165	1.338	1.333	1.325
R - 3	1.024	0.876	1.315	1.412	1.194	1.397	1.308	1.312
R - 4	1.024	0.840	1.263	1.341	1.120	1.301	1.295	1.279
R - 5	1.043	0.961	1.369	1.420	1.233	1.413	1.472	1.421
R - 6	1.182	1.092	1.541	1.621	1.361	1.549	1.568	1.555

Table IV. Peak Overpressure at Gauge Station Locations on Models F, S, and R

Gauge Station Location	Distance From GZ m	Shot Number 1 kPa	2 kPa	3 kPa	4 kPa	5 kPa	6 kPa	SHOT $\frac{1+2+6}{3}$ kPa
		Peak Overpressure P_s						
F - 1	0.890	---	4598	3123	2551	2977	4257	4428
F - 2	1.103	2385	1893	1411	880	1164	1795	2024
F - 3	1.116	1579	2061	1439	591	1209	1356	1665
F - 4	1.182	1758	1645	1055	912	1120	1432	1611
F - 5	1.194	1897	1729	1298	682	1249	1746	1791
F - 6	1.261	1694	1563	895	1001	670	1307	1521
F - 7	1.272	1351	1469	1129	727	1047	1189	1336
S - 1	0.698	1945	1522	1102	1404	1008	1374	1613
S - 2	0.931	790	647	521	677	570	455	630
S - 3	0.949	453	484	508	400	593	408	448
S - 4	1.128	557	427	421	473	491	308	431
S - 6	1.143	471	391	328	347	391	362	408
S - 7	1.325	364	309	285	313	353	234	302
								$\frac{2+6}{2}$
FF - 1	1.180	---	475	388	374	405	414	444
R - 1	0.964	421/691	277/499	290/544	388/784	408/730	247/478	262/488
R - 2	1.024	1175/961	867/791	607/944	1334/1201	1330	672	774/732
R - 3	1.024	593/819	378/776	338/872	470/1281	1192	331/608	354/692
R - 4	1.024	830/807	440/743	410/677	516/1230	767/1063	400/633	420/688
R - 5	1.043	1248/1000	1090/813	952/807	1222/1087	971	595/777	842/795
R - 6	1.182	288	201	238	366	299	213	207

Notes: Shot 1. Front Headwall Free Hinge - Concrete Roof - Structure R Separation Distance 0.666 m.

Notes: (Continued)

Shot 2. Front Headwall Taped Hinge - Concrete Roof.

Shot 3. Double Front Headwall - Concrete Roof.

Shot 4. Glass Front Headwall - Wallboard Roof.

Shot 5. Concrete Headwall and Roof - Different Charge Configuration.

Shot 6. Concrete Headwall and Roof.

Although glass is approximately the same density as concrete, it was apparently much stronger and caused some attenuation of the blast to the front relative to the masonite or concrete headwalls. Note the peak overpressures measured on Model F and Shot 4 are much lower than recorded on Shots 1, 2, (masonite headwall) or 6, on which the donor model had concrete headwalls.

An example of the overpressures versus time along the radial centerline of Model F (Gauge Stations F-2, F-4, and F-6 are presented in Figure 13 for Shot 2. Companion Stations F-3, F-5, and F-7 records from Shot 2 are presented in Figure 14.

2. Peak Overpressures Recorded on Structure S

The peak overpressures recorded on Structure S are listed above in Table IV for all six shots. Here again the values recorded on Shots 1, 2, and 6 are considered representative and average values are listed in Column 9 of Table IV. Although the donor structure had a scaled concrete roof on Shots 1, 2, and 6 the peak overpressure recorded on Structure S from Shot 6 are generally lower than the average values. No explanation can be offered for these differences. At Gauge Station FF-1 located on the opposite side of the donor from Structure S (See Figure 9) recorded a difference of ± 7 percent from the average value recorded on Shots 2 and 6.

An example of the overpressure versus time recorded at Stations S-2, S-4, and S-7 along the centerline of the roof of Structure S on Shot 2 is presented in Figure 15. Also of interest is the blast load on the doors and headwall of Structure S. This is presented in the form of overpressure versus time recorded at Stations S-3 and S-6 in Figure 16. Also presented in Figure 16 is the overpressure versus time recorded at Station FF-1 located on the opposite side of the donor at a distance slightly greater than Station S-4.

3. Peak Overpressures Recorded on Model R

The peak overpressures loading Model R are composed of many complex reflections. Any changes in any of the donor model parameters can have a significant effect on the resultant loading on the headwall of Model R. The first peak value recorded at gauge location R-1 is an indication of the magnitude of the blast wave that will be striking the headwall. Note that if the headwall thickness or hardness of the donor model is increased then more blast is propagated to the rear.

The overpressures versus time recorded on the headwall of Structure R at stations R-2, R-3, and R-4 from Shot 2 are presented in Figure 17. There is evidence from the overpressure versus time recorded at station R-4, that an incident shock wave followed by a reflected shock wave strike that position. There is also an incident and reflected shock

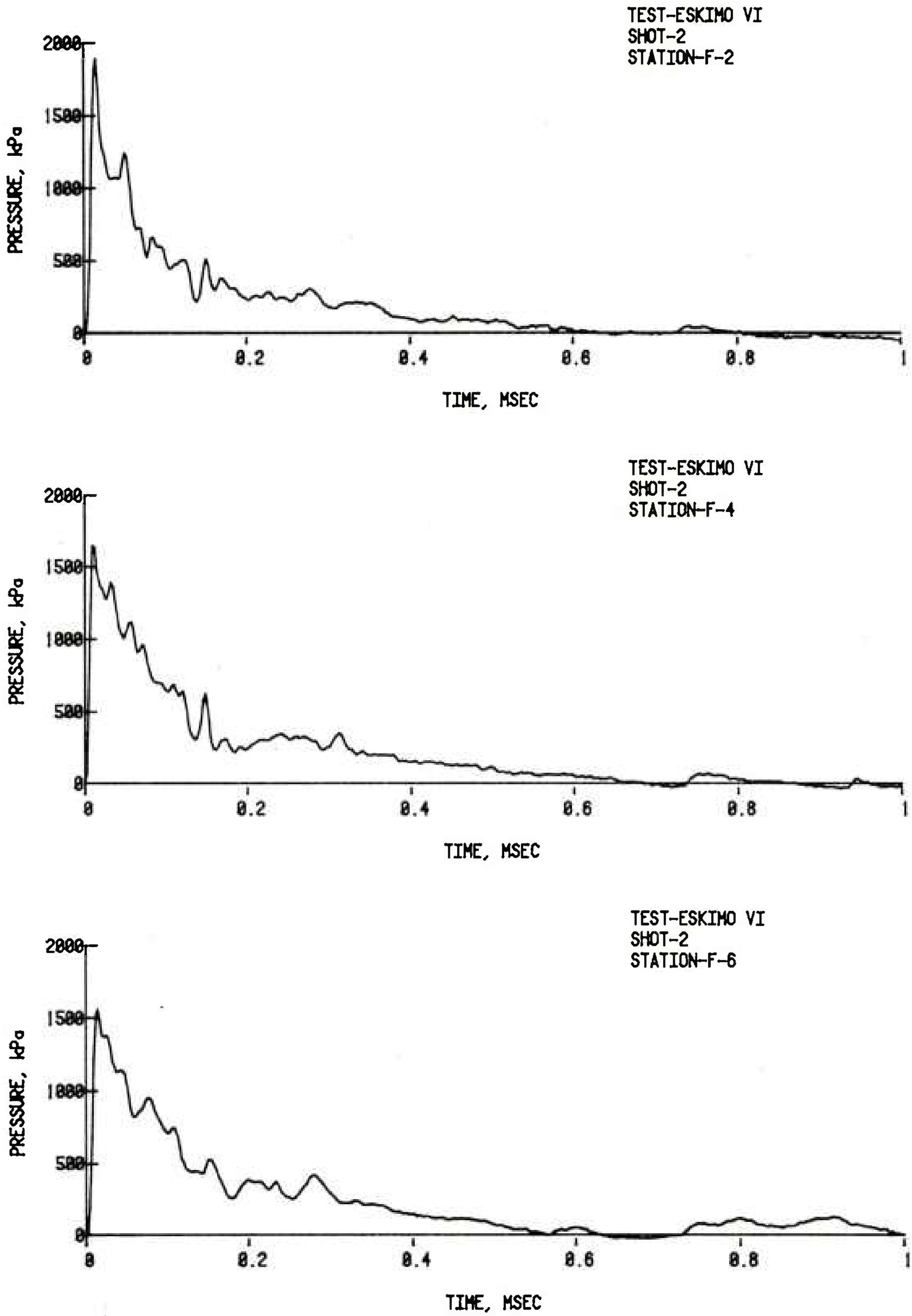

Figure 13. Overpressure versus time at Station F-2, F-4, and F-6.

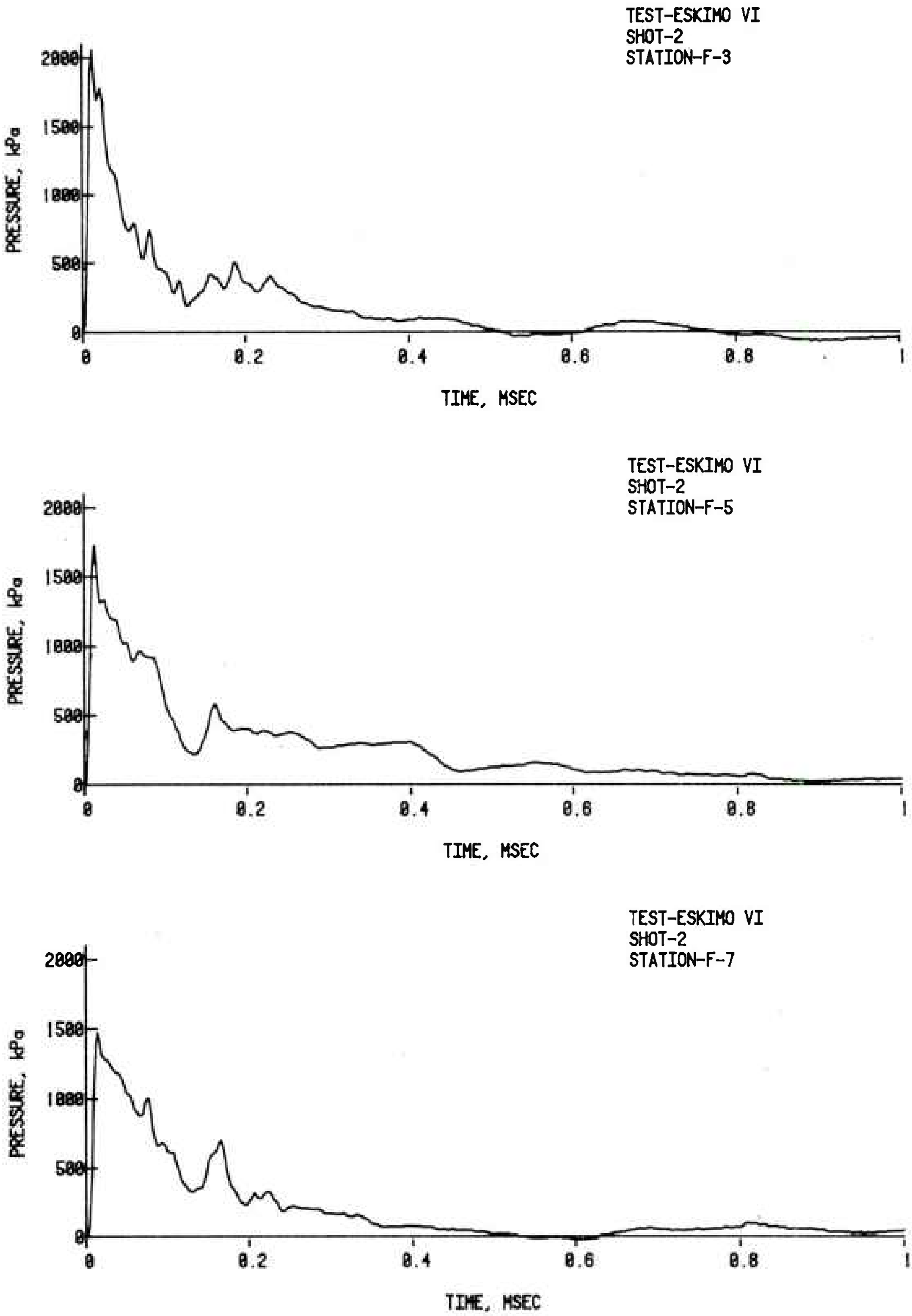

Figure 14. Overpressure versus time at Stations F-3, F-5, and F-7.

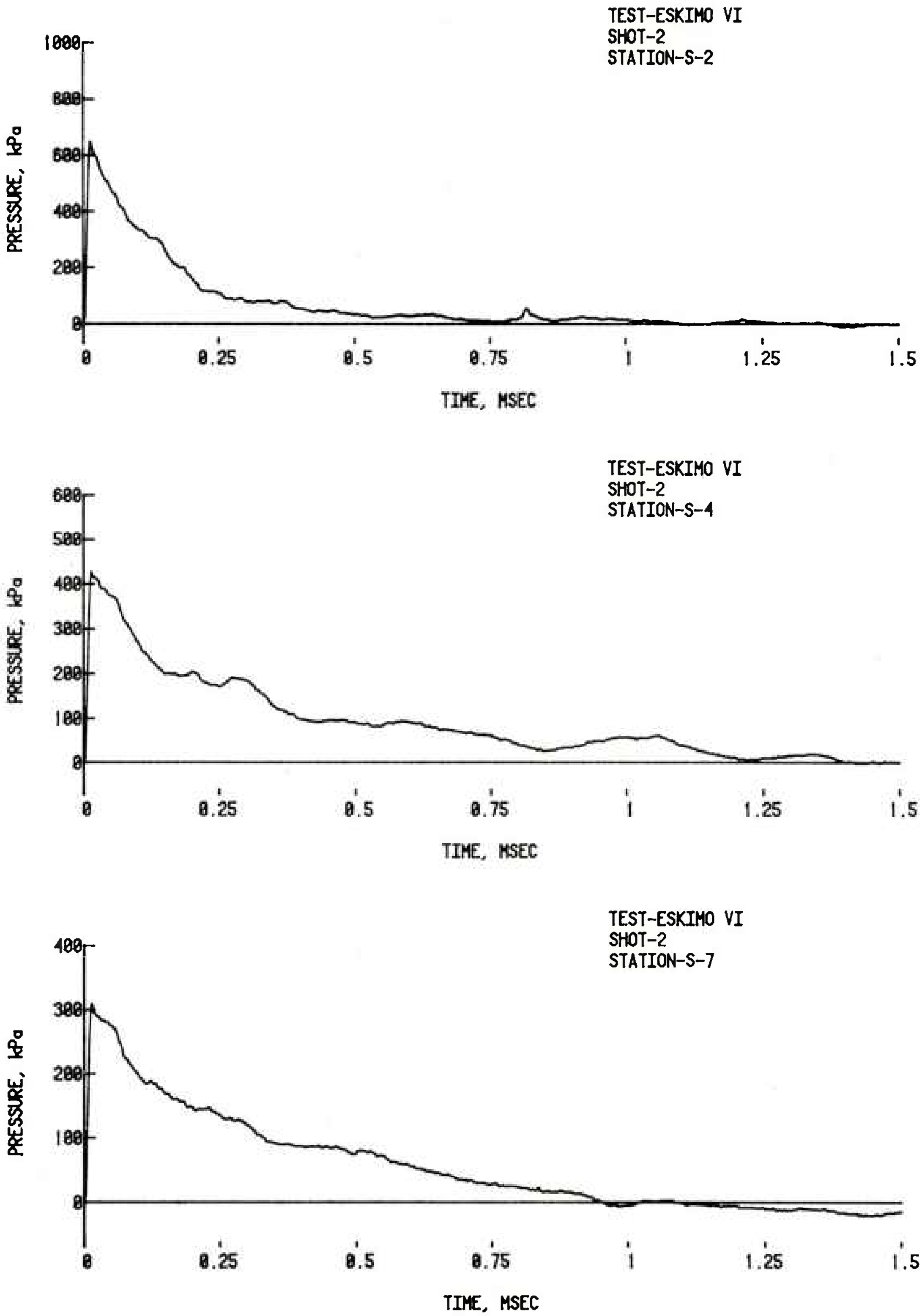

Figure 15. Overpressure versus time at Stations S-2, S-4, and S-7.

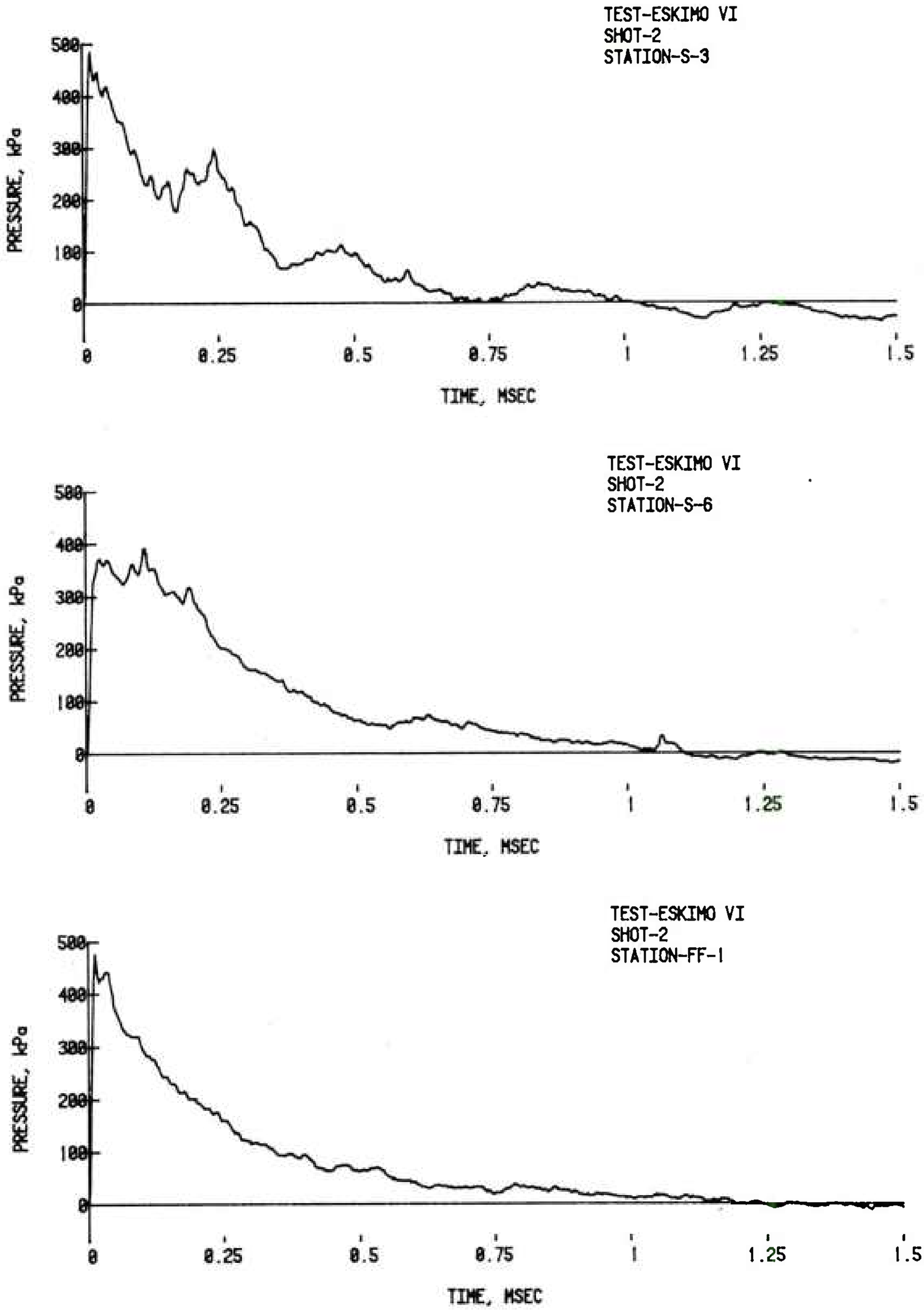

Figure 16. Overpressure versus time at Stations S-3, S-6, and FF-1.

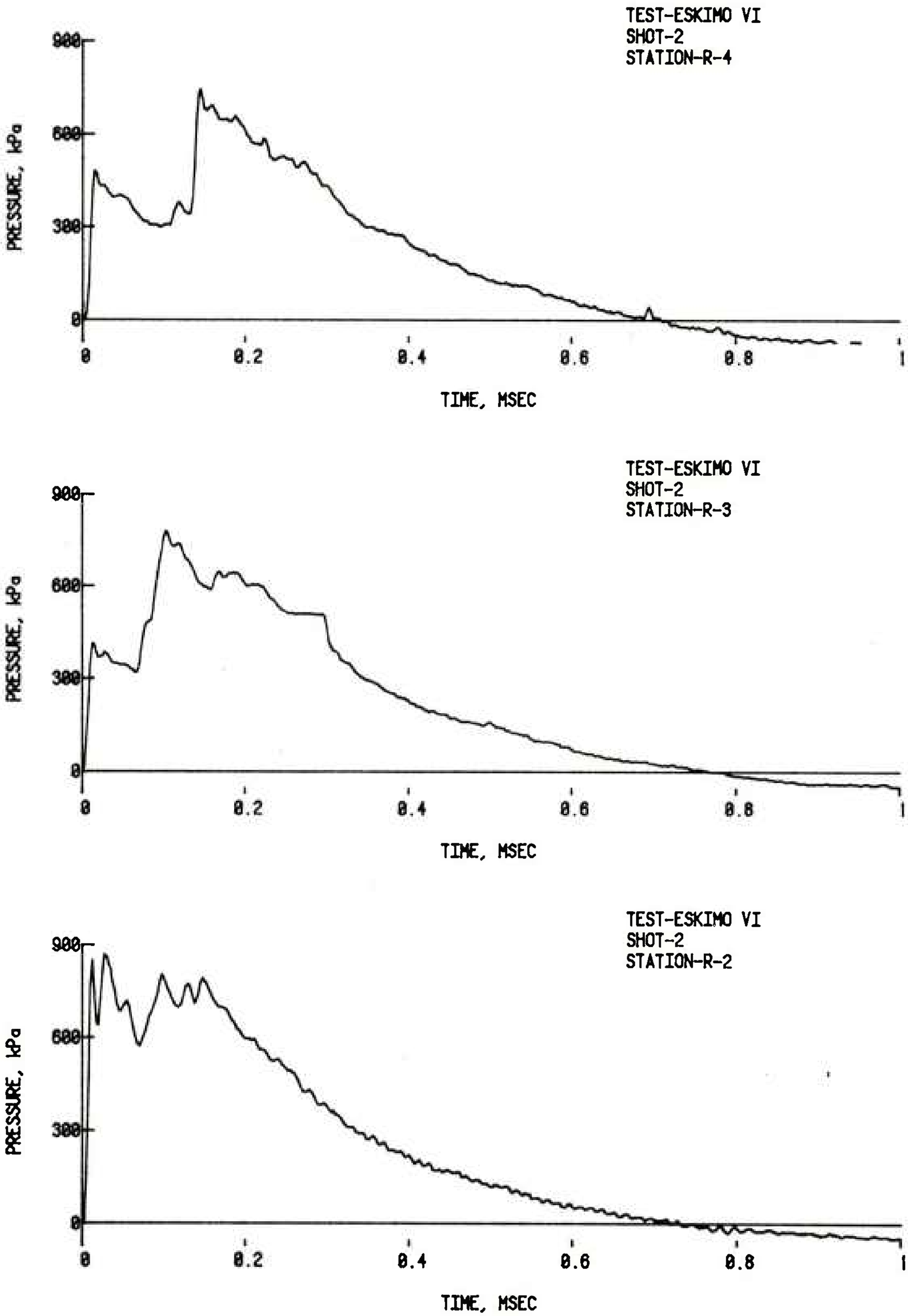

Figure 17. Overpressure versus time at Stations R-4, R-3, and R-6.

with a shorter time interval between than that which is recorded at Station R-3. At Station R-2 the record indicates it may be at, or slightly below, the mach reflection triple point.

In Figure 18 the overpressure versus time recorded at Stations R-1, located on the loading platform, R-5 located on the headwall, and R-6 located on the center of the roof, (see Figure 12) are presented. It appears that Station R-5 is also located near the triple point or slightly below it. The values of peak overpressure and impulse recorded at Station R-5 are quite similar to those recorded at Station R-2.

C. Overpressure Duration (t_+) at Gauge Station Locations on Models F, S, and R

The duration of the overpressure in a blast wave is not a precise measurement but it does indicate the length of time a structure is subjected to a positive blast load and the time at which the blast load becomes negative. The positive duration (t_+) of the blast wave for all shots are listed in Table V.

One item of interest to be noted on Structure F is that the durations recorded at Stations F-2 and F-3 are shorter than recorded at other F Stations. These stations are located near the leading edge of the roof and the combination of the expansion and rarefaction waves cause a fast decay of the peak overpressure and usually a lower impulse.

D. Overpressure Impulse (I) at Gauge Station Locations on Models F, S, and R

The impulse (I) of the blast wave imparted to the structure is one of the load parameters and is determined by intergrating the area under the overpressure versus time record. The maximum impulse should occur when the overpressure reaches zero or ambient conditions i.e., the end of the positive pulse duration. The maximum values of impulse (I) calculated from the overpressure versus time records are listed in Table VI.

1. Overpressure Impulse Recorded on Model F

The maximum positive overpressure impulse (I) determined for gauge stations on model F are listed in Table VI in units of kPa-ms. The impulse along the centerline of the roof was determined from Stations F-2, F-4, and F-6. It is of interest to note that although the peak overpressure decreases while traveling from Station F-2 to F-4 to F-6, the impulse increases. This increase is in the order of 25 percent. Gauge Station F-1 was in an extremely harsh environment i.e., the fireball. Detonation products and debris, therefore, made meaningful impulse values very difficult to determine.

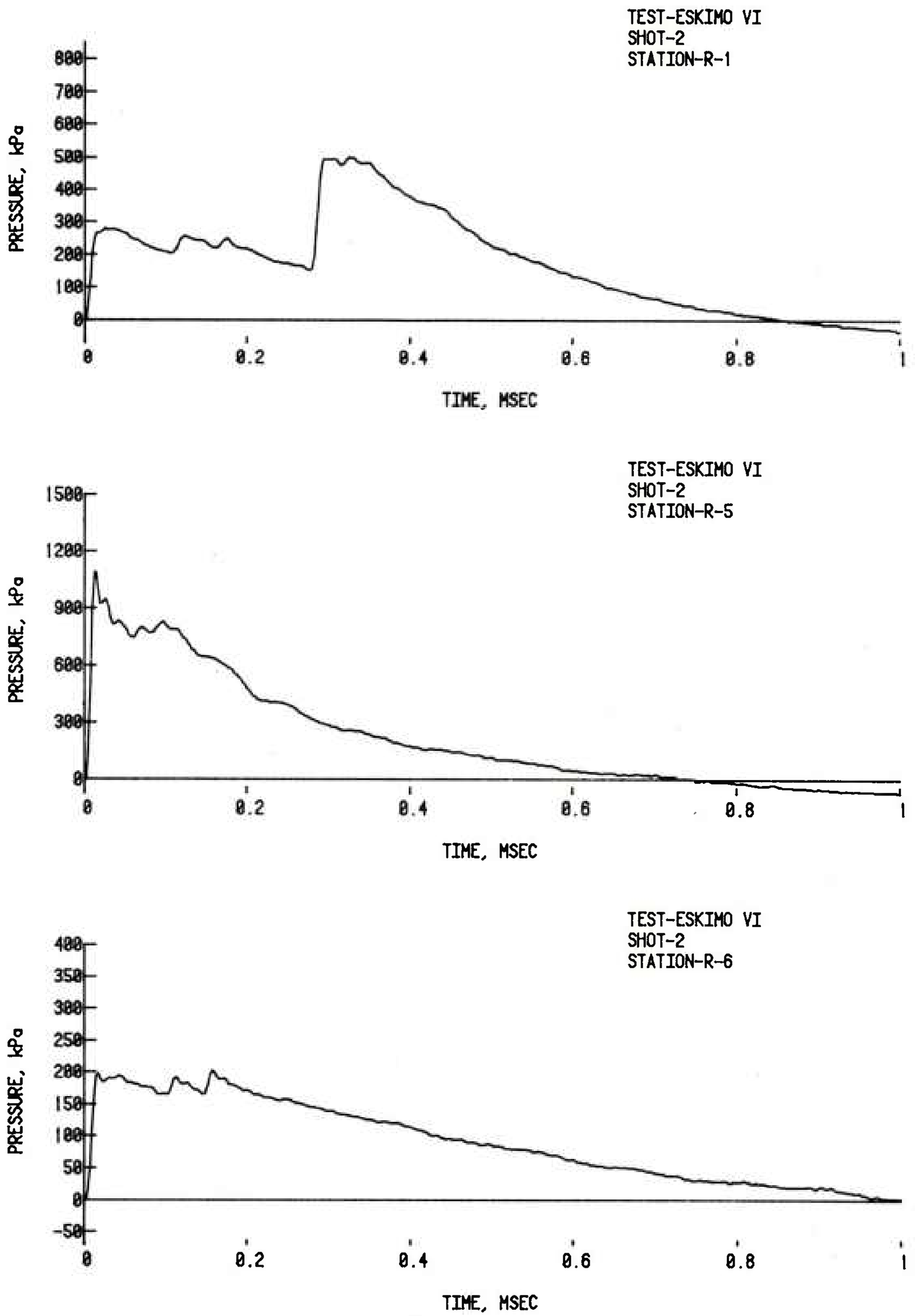

Figure 18. Overpressure versus time at Stations R-1, R-5, and R-6.

Table V. Overpressure Duration at Gauge Station Locations on Models F, S, and R

Gauge Station Location	Distance From GZ m	Sheet Number 1 ms	2 ms	3 ms	4 ms	5 ms	6 ms	AVERAGE $\frac{1+2+6}{3}$ ms
			Overpressure Duration, t_+					
F - 1	0.890	--	0.94	0.55	--	0.89	--	--
F - 2	1.103	0.65	0.63	0.96	0.90	0.87	0.86	0.71
F - 3	1.116	0.48	0.50	0.51	0.57	--	0.42	0.47
F - 4	1.182	0.94	0.87	1.18	0.98	0.89	0.83	0.88
F - 5	1.194	1.16	1.45	1.13	1.94	0.85	1.02	1.21
F - 6	1.261	1.19	1.01	1.09	1.00	1.14	1.08	1.09
F - 7	1.272	1.24	1.08	1.14	0.55	0.57	0.98	1.10
S - 1	0.698	0.71	0.55	0.62	0.59	0.63	0.59	0.62
S - 2	0.931	1.28	1.10	0.75	0.87	0.75	0.80	1.06
S - 3	0.949	0.83	1.02	1.00	0.94	0.52	0.48	0.78
S - 4	1.128	1.17	1.40	1.17	1.25	1.19	1.22	1.26
S - 6	1.143	0.81	1.10	1.06	1.15	0.76	0.68	0.86
S - 7	1.325	1.02	0.95	0.87	0.94	1.24	1.07	1.01
								$\frac{2+6}{2}$
FF - 1	1.180	--	1.25	1.32	1.22	1.11	1.18	1.22
R - 1	0.964	0.77	0.86	0.89	0.88	0.90	0.96	0.91
R - 2	0.024	0.69	0.72	0.76	0.69	0.72	0.66	0.69
R - 3	1.024	0.74	0.77	0.79	0.72	0.66	0.68	0.72
R - 4	1.024	0.55	0.71	0.71	0.65	0.72	0.66	0.68
R - 5	1.043	0.67	0.74	0.81	0.67	0.76	0.74	0.74
R - 6	1.182	0.94	1.03	0.99	0.94	0.94	1.07	1.05

Table VI. Overpressure Impulse at Gauge Station Location on Models F, S, and R

Gauge Station Location	Distance From GZ m	Shot Number 1	2	3	4	5	6	SHOT (1+2+6)/3
		Overpressure Impulse, I						
		kPa-ms	kPa-ms	kPa-ms	kPa-ms	kPa-ms	kPa-ms	kPa-ms
F - 1	0.890	---	510	399	421	---	---	---
F - 2	1.103	233	183	190	121	162	164	193
F - 3	1.116	191	184	182	84	---	104	160
F - 4	1.182	261	220	223	108	147	174	218
F - 5	1.194	293	278	249	94	156	162	244
F - 6	1.261	305	230	222	159	141	183	239
F - 7	1.272	294	195	189	90	115	145	211
S - 1	0.698	208	169	153	179	152	142	173
S - 2	0.931	118	104	99	96	76	60	94
S - 3	0.949	129	114	114	83	77	56	100
S - 4	1.128	127	136	113	117	94	77	113
S - 6	1.143	138	130	117	124	79	70	113
S - 7	1.325	102	89	80	91	90	77	89
								(2+6)/2
FF - 1	1.180	---	110	106	109	98	105	108
R - 1	0.964	184	177	184	220	208	169	173
R - 2	0.024	266	245	239	310	291	185	215
R - 3	1.024	235	223	223	282	267	174	198
R - 4	1.024	282	203	196	258	263	161	182
R - 5	1.043	255	230	229	280	249	197	214
R - 6	1.182	107	91	92	108	91	90	91

2. Overpressure Impulse Recorded on Model S

The overpressure impulse loading the roof and headwall of Model S was reasonably consistant. If an acceptor magazine is designed to survive the loading to the front of the donor (Model F), then it will be quite hard enough to survive in the side-to-side configuration.

The overpressure impulse loading on the doors and headwall of Model S is within the same range as that loading the roof. The average impulse load on the headwall and roof is 102 kPa-ms ± 11 percent. This is less than half the magnitude of the impulse load recorded on the roof of Model F.

3. Overpressure Impulse Recorded on Model R

The primary concern of loading on Model R is the blast loading on the headwall and doors. Gauge positions R-2, R-3, and R-4 were placed along a vertical centerline of the headwall to document any difference in the impulse load from top of the wall to the bottom. The same trend as reported in Reference 3 was noted on this project, i.e.; the impulse increases from the top to the bottom of the wall. Station R-5 was located at the center of the door at the right side of the headwall, slightly lower than R-2. It appeared to be below the triple point, therefore inside the Mach region. The impulse value at R-5 was always quite similar to that recorded at R-2.

Only one position was instrumented on the roof because the blast load was expected to be lower than recorded on either Model F or Model S.

IV. COMPARISONS FOR FULL-SCALE STRUCTURE

This series of tests with 1/50th scale models was conducted in order to give the design engineers and field test project officers the values of peak overpressure and impulse that might be expected on the planned ESKIMO VI. Comparisons of these model tests with other available model and full-scale tests will be made on a full-scale basis.

A. Comparison of the Blast Loading on Model F

The comparison of the peak overpressure and impulse from this series of tests will be made with those recorded on a test series conducted by the United Kingdom using 1/10th scale models and reported in Reference 4, and 1/50th scale US models reported in Reference 3. The UK models are

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4UK Report "Blast and Projections from Model Igloos", Report No. ETN 124-76, Proof and Experimental Establishment, Shoeburgness, 1976.

described in Reference 3 where other comparisons were made. There are many difficulties in making comparisons with other test series, such as the UK tests, because the charge weight to volume ratios are different by a factor of over 2.5. The geometries of the floor areas are different and the charge configurations are different. The relative location of the donor and acceptor models, the gauge locations, and the charge configurations are shown in Figure 19. With these differences in mind, a comparison of overpressures and impulses on the structure located to the front of the donor is made in Table VII.

Table VII. Comparison of Blast Loading on Model in Front of Donor (Full-Scale)

Reference	Charge Weight kg	Station Number	Distance from GZ m	Peak Overpressure kPa	Overpressure Impulse kPa-ms
3	133250	A - 4	58	1150	6550
*	158760	F - 2	55	2024	9650
4	216000	UK - 3	59	910	7520
3	133250	A - 6	71	662	7750
*	158760	F - 6	63	1521	11950
4	216000	UK - 4	74	1331	7580

*current model

The blast propagating to the front of the current model is much greater in both peak overpressure and impulse than that recorded in the UK trials, or the earlier US model studies from Reference 3. This may be partially accounted for in the charge configuration in that the long axis of the "H" shaped charge was parallel with the headwall on the current US tests and perpendicular to the headwall on the UK trials. (See Figure 19.) In Reference 3 the charge was a hemi-cylinder with the long axis parallel to the side walls of the magazine. With all of these differences noted, it is of interest that the impulse in the blast increases while traveling from the rear of the structure to the front of the structure even though the radial distance from ground zero is increasing.

B. Comparison of Blast Loading on Model S

The comparison with results from Model S will be made with oval arch magazines. Both full-scale and 1/50th scale results will be used. Data from Reference 3 and Reference 5, and the current series are listed in Table VIII. Relative gauge station locations are shown in Figure 20.

[5] *F. H. Weals, "ESKIMO III Magazine Separation Tests", Naval Weapons Center Report NWC TP 5771, February 1976.*

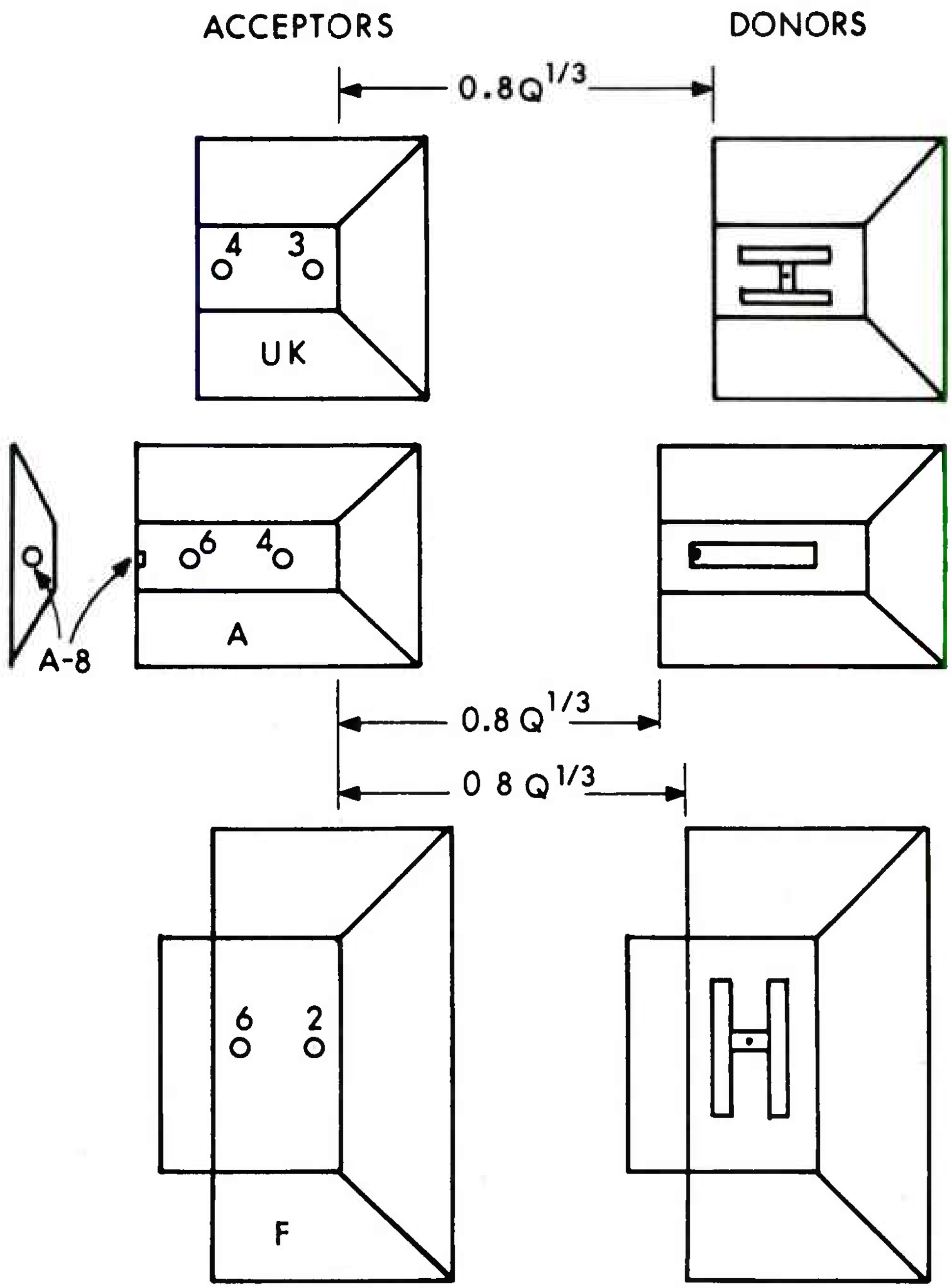

Figure 19. Relative locations of US and UK models, gauge stations, and explosive charge configurations.

Table VIII. Comparison of Blast Loading on Structure to the Side of Donor (Full-Scale)

Reference	Station Number	Distance From GZ m	Peak Overpressure kPa	Overpressure Impulse kPa-ms		Scaled Overpressure Impulse $I/Q^{1/3}$ kPa-ms/kg $^{1/3}$
5	2	22.6	830	5540	Front Slope	112
3	B-1	24.8	940	7020		137
*	S-1	34.9	1613	8650		160
5	5	28.7	1140	4670		95
5	6	31.7	550	3650	Top	74
*	S-2	46.6	630	4700		87
3	B-4	33.6	430	5650		111
*	S-4	56.4	431	5650		104
5	11	37.8	560	4290		87
*	S-7	66.2	302	4450		82
5	10-A	33.8	510	4250	Headwall	86
3	B-2	35.9	520	4640		91
*	S-3	47.4	448	5000		92
5	10-B	39.6	410	4090		83
*	S-6	57.2	408	5650		104

NOTES: Reference 5 119652 kg Tritonal equivalent
Reference 3 133250 kg Pentolite
*Current Test 158760 kg Pentolite

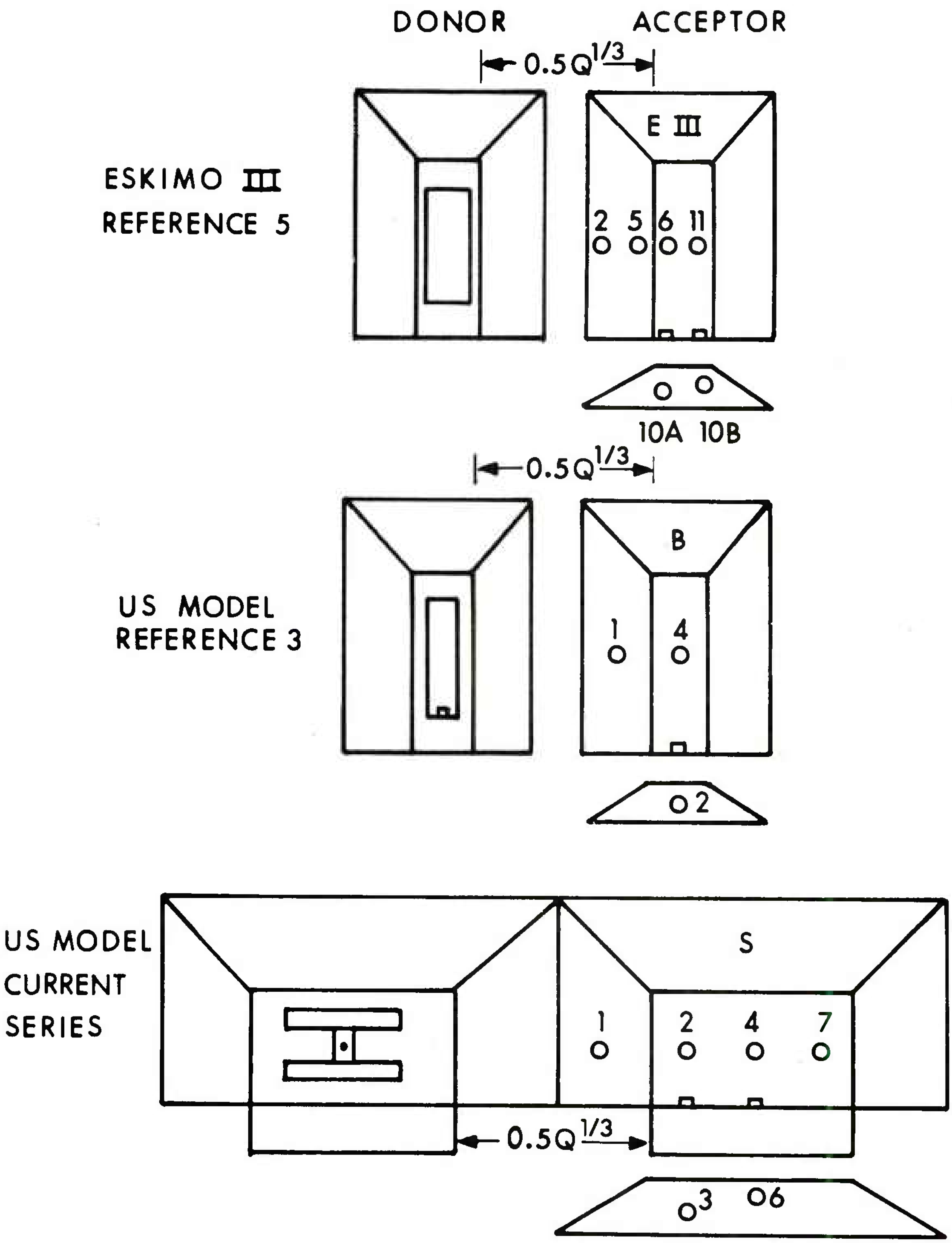

Figure 20. Relative locations of US models and full scale structures, gauge locations, and explosive charge configurations.

It should be noted that although the "safe separation" distances are consistant, the distance from the center of the charge to the gauge location is much greater on the current series of tests. The comparisons made in Table VIII appear quite consistant and imply that the average peak overpressure on the roof will be 484 kPa (70 psi) and the impulse will be 4732 kPa-ms (686 psi-ms). The average peak overpressure loading on the headwall is 459 (67 psi) and the impulse is 4726 kPa-ms (685 psi-ms). The overall blast loading on the top of the earth cover of a storage magazine in the side to side configuration is approximately the same as the loading on the headwall. This is also borne out in the scaled values of impulse listed in Table VIII where the average scaled impulse on the roof is 90.8 kPa-ms/kg$^{1/3}$ and on the headwall is 91.2 kPa-ms/kg$^{1/3}$.

C. Comparison of the Blast Loading on Model R

The doors and headwall of the acceptor model are the most vulnerable to blast loading when located to the rear of the donor. The relative gauge station locations on the current model and the models used in References 3 and 4 are shown in Figure 21. A comparison of the results full-scale from the three different test configurations is given in Table IX. The five gauge stations used in the comparisons are C-4, R-3, and 19; also, C-2 and R-5.

Table IX. Comparison of Blast Loading on Headwall of Structures to the Rear of the Donor (Full-Scale)

Reference	Explosive Weight kg	Station Number	Distance From GZ m	Peak Overpressure kPa	Overpressure Impulse kPa-ms
3	133250	C-4	51	415/1040	9080
*	158760	R-3	51	354/692	9900
4	216000	19	53	421/834	9640
3	224000	C-4	58	404/1092	11020
3	133250	C-2	51	511/782	7280
*	158760	R-5	52	842/795	10700
3	224000	C-2	58	523/853	8050

*Current Test Series

It is difficult to make a valid comparison of the peak overpressures loading the headwall of a structure to the rear of a donor because of the complex shock reflection pattern. From the recordings made on this series of tests (Table IV) it appears that the peak reflected overpressure on the headwall can reach over 1300 kPa (13 bar or 189 psi) with an

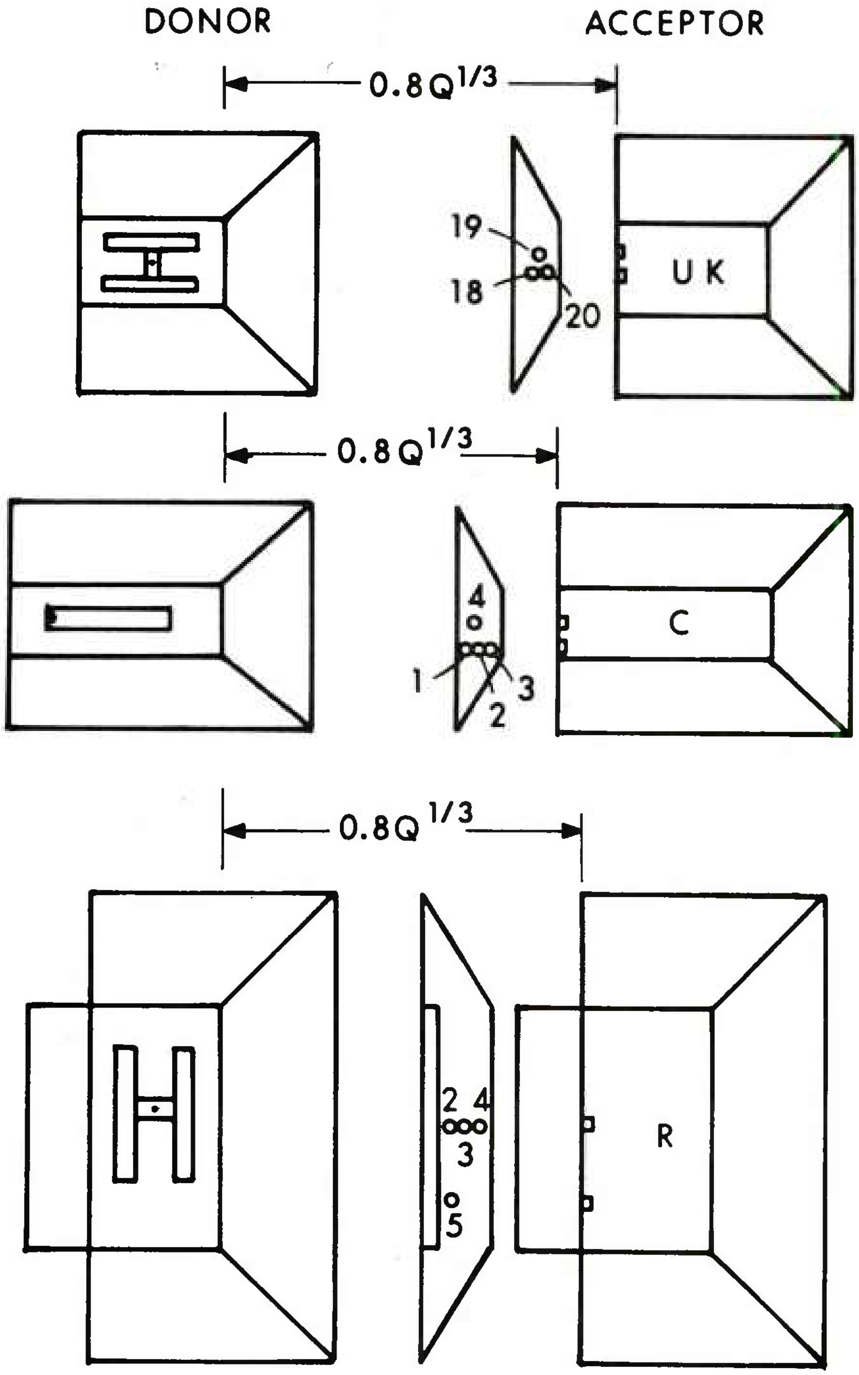

Figure 21. Relative locations of US and UK models, gauge stations, and explosive charge configurations.

impulse (Table VI) of over 14500 kPa-ms (145 bar-ms or 2103 psi-ms). The average peak reflected overpressure on the headwall derived from Shots 2 and 6 is 749 kPa (7.49 bar or 109 psi) and the average impulse for the same two shots is 10275 kPa-ms (103 bar or 1480 psi-ms).

V. PREDICTIONS FOR ESKIMO VI

The blast load predictions for ESKIMO VI structure will be treated separately because it is planned to be a one-half scale of the full size structure. All linear dimensions of the full size structure must be divided by 2 and the charge weight must be divided by 2^3 or 8. Therefore the charge weight should be 19844 kg. In order to scale the model results to the ESKIMO VI condition, all linear distances and time must follow the following scaling technique.

$$\frac{R_{1/2S}}{(Q_{1/2S})^{1/3}} = \frac{R_m}{(Q_m)^{1/3}} \quad \text{then} \quad R_{1/2S} = R_m \left(\frac{W_{1/2S}}{Q_m} \right)^{1/3}$$

and $R_{1/2S} = R_m \left(\frac{19844}{1.27} \right)^{1/3}$, $R_{1/2S} = R_m \, (25)$

where
$R_{1/2S}$ = distances for 1/2 scale structure
R_m = distance for model
$Q_{1/2S}$ = charge weight for 1/2 scale test
Q_m = charge weight for model test

Assuming standard sea level conditions model distances, arrival time, impulse and duration must be multiplied by 25 to predict the ESKIMO VI blast parameters. The volume of the ESKIMO VI structure should be the full-scale volume 1895.6 m^3 divided by 8 or 237 m^3.

Predictions of the blast parameters for the ESKIMO VI test are given in Table X for pentolite at standard sea level conditions. These values should be corrected for temperature and altitude of the test site as well as any differences in the explosive charge effectiveness.

A question concerning the overpressure and impulse that would load the headwall of Model F was asked after the model tests were concluded. An estimate is made in Table XI based on the results recorded at gauge Stations A-6 and A-8 from Reference 3. See Figure 19 for relative locations.

Table X. Predictions for ESKIMO VI

Station Number	Distance From GZ	Arrival Time	Peak Overpressure		Overpressure Duration	Overpressure Impulse	
	m	ms	kPa	psi	ms	kPa-ms	psi-ms
F - 1	22.25	8.62	4428	642	---	---	---
F - 2	27.56	11.50	2024	294	17.75	4825	700
F - 3	27.90	12.25	1665	242	11.75	4000	580
F - 4	29.55	13.00	1611	234	22.00	5450	790
F - 5	29.85	14.10	1791	260	30.25	6100	885
F - 6	31.52	14.45	1521	221	27.25	5975	867
F - 7	31.80	15.30	1336	194	27.50	5275	765
S - 1	17.45	14.90	1613	234	15.50	4325	627
S - 2	23.28	20.52	630	91	26.50	2350	341
S - 3	23.72	20.50	448	65	19.50	2500	362
S - 4	28.20	27.12	431	62	31.50	2825	410
S - 6	28.58	28.22	408	59	21.50	2825	410
S - 7	33.13	34.35	302	44	25.25	2225	323
FF - 1	29.50	32.08	444	64	30.50	2700	392
R - 1	24.10	31.88	262/488	38/71	22.75	4325	627
R - 2	25.60	33.12	774/732	112/106	17.25	5375	780
R - 3	25.60	32.80	354/692	56/100	18.00	4950	718
R - 4	25.60	31.98	420/688	61/100	17.00	4550	660
R - 5	26.08	35.52	842/795	122/115	18.50	5350	776
R - 6	29.55	38.88	207	30	26.25	2275	330

Table XI. Estimate of Blast Loading on Headwall of Structure F.

Reference	Charge Weight	Station Number	Peak Overpressure	Station Number	Peak Overpressure	A-8/A-6
	kg		kPa		kPa	
3	133250	A-6	662	A-8	117/276	0.18 & 0.42
*	158760	F-6	1521	F-8**	274/639***	

Reference	Charge Weight	Station Number	Impulse	Station Number	Impulse	A-8/A-6
	kg		kPa-ms		kPa-ms	
3	133250	A-6	7750	A-8	8940	1.15
*	158760	F-6	11950	F-8**	13742***	

Notes: * current test series
** F-8 represents headwall of Model F
*** Predicted F-8 value full-scale

Using the ratio of the peak overpressures recorded at Stations A-8 and A-6, shown in Table XI, then predicted values can be made for F-8 based on the recorded value at F-6. This gives a first peak at F-8 of 274 kPa (40 psi) and a second maximum peak overpressure of 639 kPa (93 psi). The ratio of impulse recorded at Station A-8 and A-6 is 1.15 and therefore the predicted impulse for Station F-8 would be 11950 kPa-ms x 1.15, or 13742 kPa-ms full scale, or 6871 kPa-ms (997 psi-ms) for 1/2 scale ESKIMO VI. This estimate implies that the doors and headwall of the structure located to the front of the donor may be subjected to a higher impulse load than the doors and headwall of the structure located to the rear of the donor.

VI. CONCLUSIONS

The validity of the results from the current series of tests will not be known until after Operation ESKIMO VI. But based on the correlation obtained between scaled models and full size structures in References 1, 2, and 3 it is reasonable to believe the predictions presented in Table X will be a good estimate of blast parameters that will load the acceptor structures to be used in the ESKIMO VI field test.

LIST OF SYMBOLS

t_a	Arrival time of shock wave - ms
P_S	Peak overpressure of shock wave - kPa
I	Impulse of the shock wave - kPa-ms
t_+	Duration of the overpressure of the shock wave - ms
Q	Charge weight - kg

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